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THE IRON ORES

OF THE

IRON SPRINGS DISTRICT

SOUTHERN UTAH

BY

C. K. LEITH AND E. C. HARDER

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ILLUSTRATIONS.

OUTLINE OF PRINCIPAL RESULTS.

In the Iron Springs district of southern Utah, described in this paper, sediments of Carboniferous, Cretaceous, and Tertiary ages have been intruded by large masses of andesite taken to be laccoliths. Erosion following the intrusion developed mountains out of the laccoliths, with surrounding rings of outward-dipping sediments on the lower slopes. Later extrusion of lavas covered the eroded laccoliths and sediments. Subsequent erosion has reexhumed the laccoliths and part of the sediments, leaving the lavas in a surrounding zone. The lower slopes and flats adjacent to the laccoliths are covered by the usual unconsolidated deposits of the Great Basin country. Faulting, principally of the tension type, is prevalent.

The iron ores constitute (1) fissure veins in the andesite, (2) fissure and replacement deposits along the contact of the andesite with the Carboniferous limestone, and (3) breccia cement in the Cretaceous quartzite. The larger deposits are the ones along the limestone-andesite contact. Their longer diameters in general follow the contact with rough lens shape, but there are many irregularities due to faulting and other causes.

About 1,600 exploration pits have been sunk, but the deepest goes down only 130 feet, and has not reached water level. The vertical dimensions of the deposits are therefore unknown. Their total area is 5,430,000 square feet, and their total tonnage, so far as can be measured by area and pits, is about 40,000,000 tons. Probably this estimate is much too small, for the pits do not go to the bottom of the deposits.

The ore is magnetite and hematite, containing a small amount of limonite. Much of it runs above 60 per cent in iron, but the average is about 56 per cent. Phosphorus is uniformly high. Sulphur, copper, and titanium are not present in prohibitive amounts. There is no evidence of increase in sulphur with depth, but water level has not been reached by the pits. The texture is hard and crystalline at the surface; beneath the surface the ores are relatively soft. The gangue is principally quartz or chalcedony near the surface; with depth calcite increases. Garnet, diopside, apatite, mica, hornblende, and other silicates constitute minor constituents of the ore.

The ores are closely related in origin to the intrusion of the ande-
site laccoliths. The first effect of the intrusion was the contact
metamorphism of the adjacent limestone, produced principally by
driving out its lime and magnesia carbonates and recrystallizing
the remaining constituents, but also by the introduction of silica,
iron, and soda. The net result was diminution of volume. Lime-
stone was actually fused, for residues of glass still remain. The net
density of the contact minerals is somewhat higher than the density
of the unaltered limestone, but the density of the rock as a whole is
less than that of the fresh limestone, owing to the content of glass
and the pore space. It is suggested that the fusion of the limestone
contact phase denied access to the andesite solutions, thus explaining
the lack of abundant introduction of minerals from the intrusives
along the contact. Had the temperature not reached the fusion
point of the limestone (probably about 1,000° C.), other conditions
remaining unchanged, the contact phase of the limestone might have
been left porous, affording openings for the entrance of the solutions.

The ore-bearing solutions followed shortly after the contact meta-
morphism of the limestone, and after the outer part, at least, of the
andesite laccoliths had crystallized, as shown by the occurrence of
ore in fissures in the andesite and limestone contact phase. The ore-
bearing solutions carried silicates similar to those previously formed
in the limestone contact. The conspicuous feature was the intro-
duction of soda by the ore-bearing solutions into both limestone and
andesite along the contact. A comparison of the alteration of the
andesite next to the ore with its alteration by weathering brings out
clearly the effect of the ore-bearing solutions.

A graphic method of comparison of the fresh and altered rocks
brings out various possibilities in the interpretation of analyses.

A consideration of the temperatures of crystallization of some of
the silicates deposited with the ores and possible pressures resisting
the solutions seems to indicate a probability that the solutions may
have been vapors and that they were pneumatolytic after-effects of
the andesite intrusions.

It is suggested that the iron was carried as ferrous chloride, which
became oxidized at a temperature above 500° C. by breaking up
associated water and simultaneously developing free hydrogen.
Precipitation came about partly by the neutralization of the acid
when it came into contact with the limestone, and partly by the
evaporation of the acid with the water which would accompany the
diminution of temperature and pressure as the solutions left the andes-
ite. The conspicuous introduction of soda into wall rocks suggests
further that the same solution carried salt. This would be decom-
posed by silicic acid and the soda be deposited as sodium silicate,
largely albite, the form in which it is now found.

The ore-filled fissures in the andesite and limestone resulted from the cooling of the andesite mass, which developed stretch fractures within the mass and pulled it away from the limestone wall as a casting away from the mold. Where the ore-bearing solutions reached the unaltered limestone rather than the silicated contact phase of the limestone the ore replaced the limestone. Where they reached the overlying quartzite they filled fractures.

A considerable secondary concentration may be traced to the Tertiary lavas which once covered the ore deposits. The ores were coarsely recrystallized and chalcedony was introduced as a gangue material in place of calcite. No heavy silicates were introduced. The concentration under the influence of the lavas is a relatively shallow one, which can be fairly separated from the deep primary concentration.

The entire effect of weathering is not known, because the ores have been observed only above water level. Above this they are porous, suggesting that there may have been a considerable amount of solution of the gangue materials down to this point. Calcite has obviously been leached near the surface and deposited farther down; apatite has been altered to osteolite; small amounts of sulphides have been oxidized and partly removed; limonite has developed in thin films along the margins of cavities and along fissures. In general, however, the obvious relations of the characteristics of the ore to conditions other than weathering seem to indicate that the iron oxides themselves have been little affected by weathering.

Inferences as to the extension and shape of the ore deposits in depth are drawn from a consideration of origin. The ores may have a considerable depth. The ores are not likely to be so thick along the contact on upper slopes, because gravity tended to close the openings formed by the cooling of the andesite mass. There seems to be no reason why ore should not be found at the limestone-andesite contact at places where the contact is now overlain by Cretaceous quartzite.

The Iron Springs deposits are typical of many other western iron-ore deposits, and it is believed from personal observation that their origin has essential features in common. Description is made of the structure of ore of similar occurrence in the adjoining Bull Valley district, and reference is made to deposits regarded as belonging to the same class in other parts of the West.

THE IRON ORES OF THE IRON SPRINGS DISTRICT OF SOUTHERN UTAH.

By CHARLES KENNETH LEITH and EDMUND CECIL HARDER.

CHAPTER I.

INTRODUCTION.

PURPOSE OF THE INVESTIGATION.

The enormous and rapidly increasing consumption of iron ore in the United States during the last few years has led to careful inventories of available supplies, both in producing districts and in relatively unknown fields, with the result in general of emphasizing the limitation of the deposits now worked and of pointing out the necessity for the early exploitation of new ones.. Up to the present time less than 2 per cent of the iron ore mined annually has come from west of Mississippi River, but there have long been known in that region large deposits of iron ore which have not been exploited because of lack of transportation facilities or distance from consuming centers. The part these deposits are to play in meeting the future demand for iron ore, the possibilities or probabilities of finding other large deposits in the West, and the geological features of significance in connection with these questions remain largely to be ascertained.

Mr. Leith began a general geological reconnaissance of western iron ores in 1903 and continued it during 1904, 1905, and 1906, visiting some of the better known ore deposits of Utah, Colorado, Wyoming, Washington, British Columbia, California, and Missouri. It early became apparent to him, as it had been apparent to others, that the iron-ore deposits of the West are prevailingly of a distinct and uniform type—an irregular replacement of limestone near the contact with igneous rocks, or a vein filling in both limestone and igneous rock—a type fundamentally different from that of the important producing districts east of Mississippi River, and probably of different origin. The deposits of the Iron Springs district of southern Utah were selected as typical of this class of deposits, well located for study, and of such size and quality as to warrant the belief that their exploitation

would follow in a short time; accordingly, detailed geological work was begun in this district in 1905 by Mr. Leith, with E. C. Harder and Frank J. Katz as field assistants, and was continued during the early part of the field season of 1906 by E. C. Harder and Freeman Ward, the senior author being with the party for three weeks. The results of this work are presented in the following pages. It is believed that they will be found to apply in their essential features to many other deposits of the same general class in western United States.

PREVIOUS WORK.

Lying near the northwest side of the High Plateau region and in the southeast part of the Basin Range province, the Iron Springs district has received passing attention from Powell (1875 and 1879),[a] and Dutton (1880 and 1882)[b] and associates in their general surveys of the High Plateaus and Colorado River, and from the geologists of the Wheeler Survey—Howell (1875),[c] Gilbert (1875),[d] and Marvine (1875).[e] Their maps and descriptions are necessarily so generalized that they are of little value in detailed study of the district under discussion. They are important, however, in establishing a basis for the general correlation of formations.

The Powell Survey prepared a reconnaissance topographic map of southern Utah, part of which, covering the Iron Springs district, is included in the St. George sheet of the United States Geological Survey. While this is too much generalized to be of use in detailed mapping, it expresses the general topographic and geographic relations of the Iron Springs district to the surrounding territory.

Howell (1875)[f] was the first of the early geologists to make anything like a specific description of the Iron Springs district and its iron-ore deposits. He includes analyses of the ores by C. E. Dutton.

In 1880 the deposits received attention from J. S. Newberry,[g] then America's leading authority on iron ore. He describes the deposits as constituting "perhaps the most remarkable deposit of iron ore yet developed on this continent," and refers the sediments of the district

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[a] Powell, J. W., Exploration of the Colorado River of the West and its tributaries; explored in 1869, 1870, 1871, and 1872, under the direction of the Secretary of the Interior; U. S. Geog. and Geol. Surv. Rocky Mountain Region, Washington, 1875, 291 pp.; Report on the lands of the arid region of the United States, with a more detailed account of the lands of Utah; U. S. Geog. and Geol. Surv. Rocky - Mountain Region (2d ed.), 1879, 195 pp.

[b] Dutton, C. E., Report on the geology of the High Plateaus of Utah; U. S. Geog. and Geol. Surv. Rocky Mt. Region, 1880, 307 pp.; Tertiary history of the Grand Canyon district; Mon. U. S. Geol. Survey, vol. 2, 1882, 264 pp.

[c] Howell, E. E., Report on the geology of portions of Utah, Nevada, Arizona, and New Mexico, examined in the years 1872 and 1873; U. S. Geog. Surv. W. 100th Mer., vol. 3, Geology, 1875, pt. 3, pp. 227–301.

[d] Gilbert, G. K., Report on the geology of portions of Nevada, Utah, California, and Arizona examined in the years 1871 and 1872; U. S. Geog. Surv. W. 100th Mer., vol. 3, Geology, pt. 1, 1875, pp. 17–187.

[e] Marvine, A. R., Report on the geology of route from St. George, Utah, to Gila River, Arizona, examined in 1871; U. S. Geog. Surv. W. 100th Mer., vol. 3 Geology, pt. 2, 1875, pp. 189–225.

[f] Op. cit., pp. 261–263.

[g] Newberry, J. S., The genesis of the ores of iron: School of Mines Quart., Nov., 1880, pp. 9–12.

doubtfully to the Lower Silurian. Both the ores and the andesite (called granite) he regarded as metamorphosed sediments.

The Iron Springs deposits figure in the Tenth Census report (1886),[a] where they were mapped and described by Putnam from an economic standpoint. He referred to them as "probably the largest mass of iron ore in the whole West."

The district lies close to the southeastern shore of Lake Bonneville, and accordingly it appears on the maps accompanying Gilbert's Bonneville report (1890).[b]

The physiographic record of the region to the east and south of the Iron Springs district was the subject of careful study in 1904 by Huntington and Goldthwait[c] under the direction of W. M. Davis.

The senior author[d] of the present report has published two short statements of the results of his examination of the district (1903 and 1906).

A general economic account of the district with special reference to the chemistry of the ores was made by Fred Lerch (1904).[e]

A considerable amount of exploration of the district has been done in recent years for commercial interests, the results of which have not been published, but which are incorporated in the present report.

ACKNOWLEDGMENTS.

[a] Putnam, B. T., Notes on the samples of iron ore collected west of the one hundredth meridian: Tenth Census U. S., vol. 15, Mining Industries, 1886, pp. 469–505.

[b] Gilbert, G. K., Lake Bonneville: Mon. U. S. Geol. Survey, vol. 1, 1890, pp. 438.

[c] Huntington, Ellsworth, and Goldthwait, J. W., The Hurricane fault in the Toquerville district, Utah: Bull. Mus. Comp. Zool., Harvard Coll., No. 42 (Geol. ser., vol. 6), 1904, pp. 199–259.

[d] Leith, C. K., Iron ores in southern Utah: Bull. U. S. Geol. Survey No. 225, 1904, pp. 229–237; Iron ores of the western United States and British Columbia: Bull. U. S. Geol. Survey No. 285, 1906, pp. 194–200.

[e] Lerch, Fred, The iron-ore deposits in southern Utah: Iron Trade Review, May 19, 1904, pp. 49–50.

CHAPTER II.

GEOGRAPHY, TOPOGRAPHY, AND GENERAL GEOLOGY.

GEOGRAPHY AND TOPOGRAPHY.

The Iron Springs district lies between longitudes 113° 10′ and 113° 26′ 30″ and latitudes 37° 35′ and 37° 47′ 30″, in Iron County, southern Utah, about 250 miles south of Salt Lake City and 550 miles from the harbor of San Pedro, Cal., on the Pacific Ocean. The San Pedro, Los Angeles and Salt Lake Railroad runs within 22 miles of the district on the west, Lund being the nearest station. The district can also be reached by way of a spur of the Denver and Rio Grande Railroad running down to Marysvale, 80 miles northeast of the district, thence on by stage.

The area (see fig. 1) lies near the eastern margin of the Basin Range province and includes several basin ranges and hills, principal among which are the Harmony Mountains, Iron Mountain, Antelope Range, Granite Mountain, The Three Peaks, and Swett Hills (Pl. I, pocket). To the south are the Pine Valley Mountains. Immediately west, north, and east of the district lies the desert, beyond which on the west and north are other basin ranges, and on the east, 12 miles away, is the Hurricane fault scarp of the High Plateaus. On the southwest the district is continuous with a series of ranges and hills extending west of the Pine Valley Mountains well into Nevada.

The elevation ranges from 5,300 to 8,000 feet.

The drainage is through small creeks leaving the mountains and hills and soon losing themselves in the desert.

The tops of the Harmony Mountains retain snow until the middle of summer, and consequently have an abundance of vegetation, such as yellow pine, fir, cottonwood, quaking aspen, and mountain mahogany. The tops and slopes of the other mountains are dry and are covered with a growth of scrub cedar and piñon. Shrubs, sagebrush, and several species of cacti are also abundant, but grasses are lacking. The surrounding desert presents the variety of sagebrush, rabbit brush, greasewood, and shad scale characteristic of the desert elsewhere in the Great Basin.

The location of the Iron Springs district affords unusual opportunities for the study of Basin Range structure, the relation of the Basin Ranges to the High Plateaus, and the associated problems. From a scenic standpoint also the district is difficult to surpass, affording a view of the massive Pine Valley Mountains, the desert
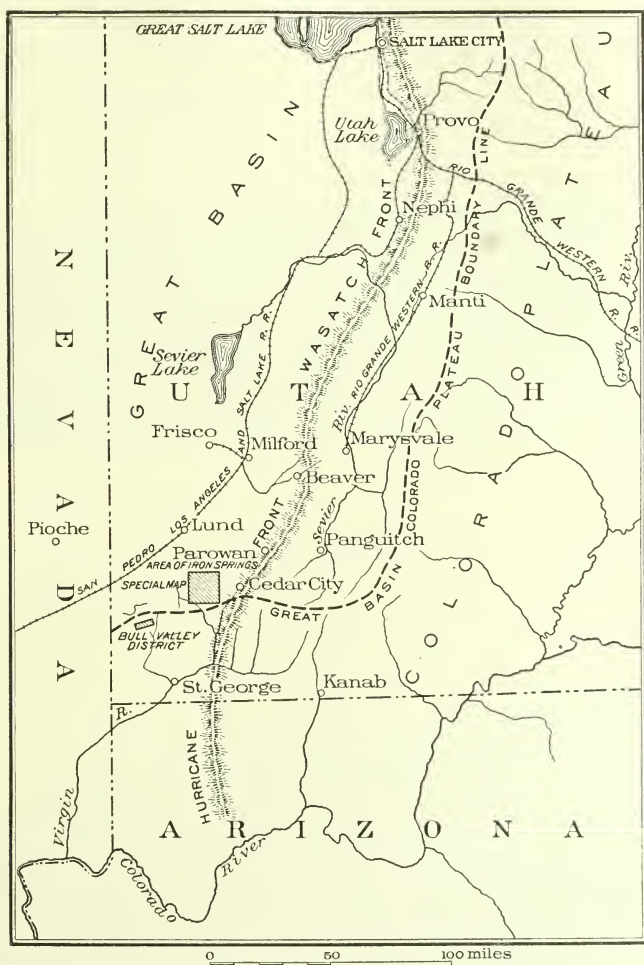
Fig. 1.—Sketch map of parts of Utah, Arizona, and Nevada, showing geographic relation of Iron Springs district to physiographic regions.

in its typical development, and the still more striking, brilliant-colored escarpments of the High Plateaus, notched immediately opposite the Iron Springs district by Cedar Canyon (Coal Creek Valley), which rivals in form and beauty of coloring the canyon of the Virgin, 50 miles to the south, and even the Grand Canyon, 100 miles to the south.

GENERAL GEOLOGY.

The dominating geological features of the district are 3 large andesite laccoliths, constituting The Three Peaks (Pl. VII, *A*), Granite Mountain, and Iron Mountain, lying in a northeast-southwest line across the area mapped. Three unconformable sedimentary series, aggregating 4,000 feet in thickness, outcrop in successive rings around these laccoliths (Pl. VII, *B*), dipping outward asymmetrically, very steeply at the contact, less steeply farther away. Still farther from the laccoliths lava flows 2,000 feet thick rest in nearly horizontal attitude on the tilted sedimentary rocks. These general relations are modified by faulting. All of the rock formations of the district are more or less covered on the middle and lower slopes by unconsolidated and partly consolidated erosion débris, both aqueous and subaerial, which spreads out on the lower ground to make the deserts. The detailed succession is shown in fig. 2.

The laccoliths are exposed only in their upper parts—at no place has erosion shown their bottoms in section. The rock is an andesite of remarkably uniform texture and composition. Within the area of the laccoliths are a few veins of iron ore and fault blocks of ore and Carboniferous and Cretaceous sediments.

In contact with the laccoliths for the most part is Carboniferous limestone, a pure, dense, blue limestone, with a few feet of sandy material appearing locally at the base. The contacts are at most localities nearly vertical, this being due partly to faulting and partly to the fact that erosion has cut down to the sides of the laccoliths, exposing the vertical part of their contact. Locally, where erosion has not gone down so far, the limestone dips distinctly away from the andesite at an angle as low as 10°. The limestone is altered at the contact with the laccolith for a maximum of 1,000 feet, as measured on the erosion slopes, by loss of carbonates, development of anhydrous silicates, and replacement by ore.

Cretaceous sediments outcrop in a zone outside of the Carboniferous limestone, except where locally they are faulted down against the laccolith, or where the laccolith has penetrated the Cretaceous and erosion has not yet cut down to the Carboniferous limestone, as on the west side of Iron Mountain. The Cretaceous rocks are principally sandstone, with layers or lenses of shale, conglomerate, and limestone breccia. At the contact with the laccoliths the sandstone has been indurated and amphibole has developed.

The relations of the Cretaceous sandstone to the underlying Carboniferous limestone are those of apparent conformity, but the contact is rendered somewhat obscure by the presence of shale at the base of the Cretaceous sandstone. The lower portion may be in part Jurassic, but separation could not be made. The greatly varying
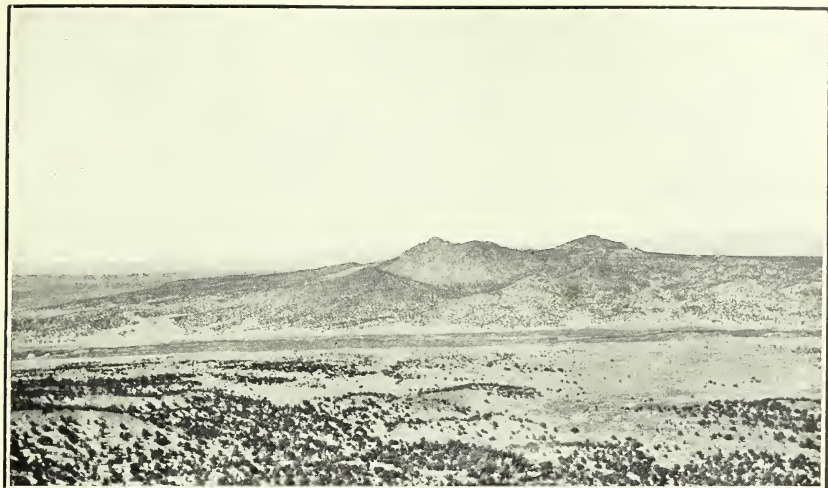
A. IRON SPRINGS VALLEY AND THE THREE PEAKS. FROM LINDSAY HILL.

B. CRETACEOUS SEDIMENTS DIPPING AWAY FROM THE ANDESITE ON SOUTHWEST CORNER
OF THE THREE PEAKS LACCOLITH.

thickness of the Carboniferous limestone may be due partly to erosion and partly to intrusion of andesite at different horizons. If it represents erosion, this is evidence of unconformity. Notwithstanding the conformity of structure, it is not unlikely that there may be a hiatus between the two systems, for the correlation of
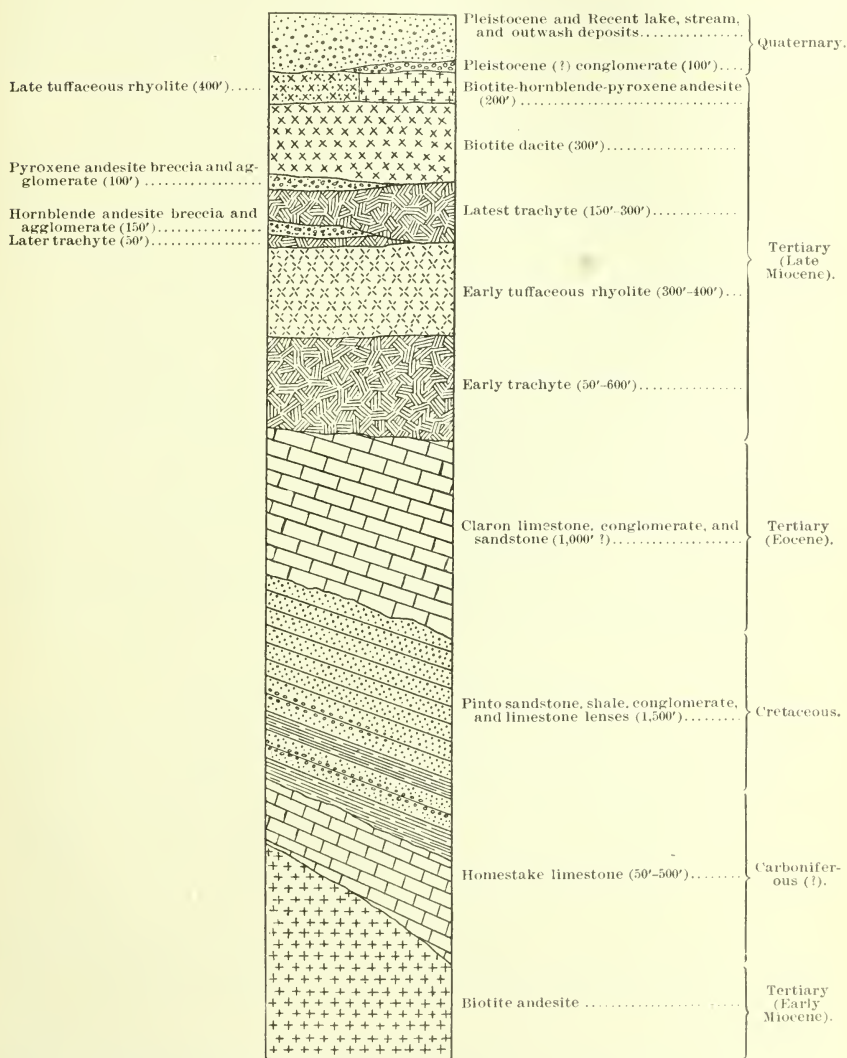
FIG. 2.—Geologic column of the Iron Springs district.

the two is fairly well based, and the Permian, Triassic, and some Jurassic sediments are lacking between them.

The Eocene series outcrops in a zone still farther away from the laccoliths. It consists of limestone and conglomerate, characterized

principally by pink and bright-red colors. A basal conglomerate separates it from the Cretaceous sediments below. The dip of the Cretaceous averages about the same as that of the Tertiary, but there is a marked erosion unconformity between them.

Miocene lavas and tuffs rest nearly horizontally upon the eroded edge of the Eocene sediments and to a less extent upon the Cretaceous.

In the northwestern part of the area, near Antelope Springs, a Pliocene or Pleistocene fluviatile deposit occupies an embayment in the lavas. It is principally a conglomerate containing fragments of the lavas, of the earlier andesite laccolith, and of the sediments.

Pleistocene and Recent lake, stream, and outwash deposits, consisting of gravels, sands, and clays derived from the erosion of all of the rocks of the district, occupy nearly half of the area and mask the rock formations of the lower ground. As a whole this material is a result of disintegration to a larger extent than of decomposition. It is accumulating with extreme rapidity. The hillsides are covered with it and during heavy rain storms a great mass of débris, including fragments many feet in diameter, creeps down the slopes. The finer material is carried down by the torrents and distributed in broad, low fans on the deficient slopes below. The apparently flat "desert" is made up principally of overlapping fans. An hour's heavy rain brings about a conspicuous modification of alluvial fans or other deposits at these places. The extreme rapidity of erosion and transportation in an arid region has often been described, but the amount of material moved in a few hours can scarcely be realized without direct observation.

FAULTS, JOINTS, AND FISSURES.

That faulting complicates the elementary relations above sketched is apparent from an inspection of the general map (Pl. II, pocket). Fault scarps are common. Streams or canyons follow faults and joints, especially the former, so prevailingly that in the mapping faults were looked for whenever a canyon was encountered. Faults have been mapped only where they could be actually proved to exist by the relations of the rock formations, otherwise they are not shown on the map, even where their absence or their abrupt termination looks structurally improbable. It is certain that many have been missed.

The larger and more conspicuous faults have a prevailing north-south trend, but many have other directions, as summarized in fig. 3. At several localities, especially near the ore deposits, a tendency in the faults to follow about the periphery of the andesite laccoliths is observable.

The fault planes are vertical, or nearly so. The displacements vary from vertical to horizontal—principally the former in the faults

mapped.   The maximum vertical displacement known is 2,000 feet; the horizontal displacement is unknown.   Hinge faults, the displacement at one end of which is opposite to that at the other, were found locally in the lava area.   It is probable that many of the faults with a displacement parallel to the dip of the beds have not been mapped because not detected.   Allowing for a considerable unknown horizontal component of displacement, there remains a probable dominance of vertical movement sufficient to indicate that the net result
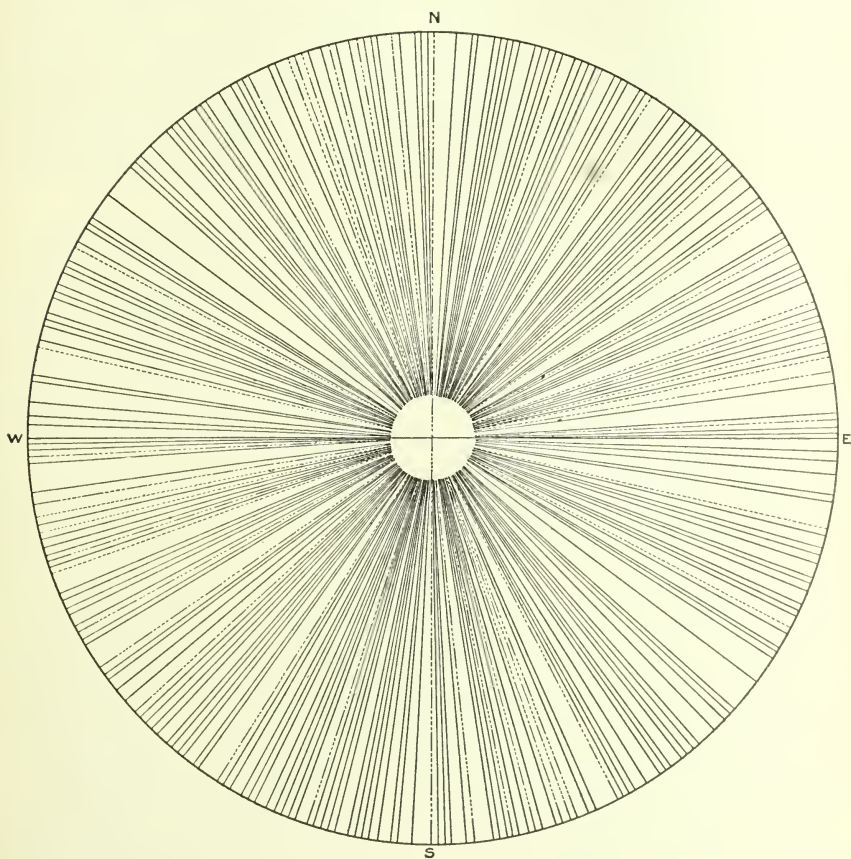
FIG. 3.—Plat of faults and iron-ore veins in the Iron Springs district. Solid lines show faults; dotted lines, iron-ore veins; and solid and dotted lines, faults and iron-ore veins.

of the faulting has been the extension of the area; in other words, the faults are primarily tension phenomena.

Conspicuous in the andesite are fissures, some of them filled with ore, which curve, taper, branch, and parallel themselves in such a manner as to suggest that they are stretch fractures.   In the Three Peaks andesite area there is a conspicuous parallel fracturing spaced at intervals of a fraction of an inch to a number of feet.   In the neighborhood of ore veins they have the same trend as the veins.

The origin of the faults and other fractures is believed to have been principally due to the successive extension, shortening, and settling accompanying the intrusion and the cooling of the laccoliths—the origin cited by Spurr for some of the faults of the Tonopah district. The faults are tension phenomena, and are so numerous and so intricate in their intersections that it is easier to explain them by somewhat local strains accompanying cooling than by strain on the district as a whole. The faults outlining the periphery of the andesite and the stretch fractures within the andesite may be ascribed definitely to this cause. A rough calculation of the cubic shrinkage of a mass of andesite the size of the Iron Mountain laccolith in crystallizing from a glass to andesite indicates a horizontal radial shortening of between 200 and 500 feet, depending upon the depth assumed for the mass—in any case a large enough factor to be important in the development of fractures.

So far as the faulting was due to the intrusion and cooling of the andesite, it followed the intrusion closely and is of Tertiary age.

Other faults cut the lava flows and are therefore considerably later than the laccolith intrusions. These faults are, from their nature, probably in part due to the cooling of the lavas.

Certain of the larger faults, and especially those having north-south directions, showing great extent and continuity across both igneous and sedimentary formations, may be caused otherwise than by cooling either of laccoliths or of lavas. They seem to belong more to the order of deformation producing the Hurricane fault to the east than to the deformation associated with local igneous action. The whole Iron Springs district represents a downthrow on the west side of the Hurricane fault. The stresses have affected large areas. There can be little doubt that these great faults are essentially tensional in nature, but the cause of the tensional stresses is not clear from the facts available in this area, nor, judging from the literature, from the facts available elsewhere in the Great Basin. King [a] first emphasized the parallelism of faults with folds in the Great Basin region, and Gilbert [b] suggested that the Great Basin faults are but the surface expressions of folds similar to those of the Appalachian Mountains. The parallelism of the faults with axial planes of folds is shown also by the work of Huntington and Goldthwait [c] on the folded and faulted district separating the Great Basin from the high plateaus southeast of the Iron Springs district, where the fault planes and displacements are nearly vertical and the phenomena in general are those of tension.

The correlation of the tensile nature of the strike faults with the shortening of the lithosphere shown by the folds seems possible only

a King, Clarence, Systematic geology: U. S. Geol. Explor. 40th Par., vol. 1, 1878, p. 735.

b Gilbert, G. K., Report on the geology of portions of Nevada, Utah, California, and Arizona, examined in the years 1871 and 1872: U. S. Geog. Surv. W. 100th Mer., vol. 3, Geology, pt. 1, 1875, p. 62.

c Huntington, Ellsworth, and Goldthwait, J. W., The Hurricane fault in the Toquerville district, Utah; Bull. Mus. Comp. Zool., Harvard Coll., No. 42 (Geol. Ser., vol. 6), 1904, pp. 199–259.

by assuming tension along the crests of anticlines, resulting in strike joints and faults. It may be pointed out that no considerable uplift of the arch necessarily precedes faulting of this kind, for the faulting may follow the tendency to uplift so closely that the two movements are nearly simultaneous. It is of interest in this connection to note that Huntington and Goldthwait have developed the fact that the relative vertical movements produced by the folds whose axes are parallel to the Hurricane fault were in opposite directions from those produced by subsequent faults. In the former case the west or Great Basin side was uplifted with reference to the east or High Plateau side, while in the subsequent faulting the Great Basin became the downthrow side, suggesting a drop of the anticline—that is, normal faulting consequent on the folding.

SEQUENCE OF GEOLOGIC EVENTS.

The principal features in the development of the present geological and physiographic features of the district have been in order as follows:

(1) Deposition of Carboniferous limestone, with thin fragmental base, on basement unknown in this district.

(2) A period of nondeposition, perhaps erosion, followed by deposition of Cretaceous and perhaps some Jurassic sandstone with layers of shale, conglomerate, and limestone.

(3) An erosion interval, followed by deposition of Eocene limestone and conglomerate in an inclosed basin. The conditions are principally those of shallow water, strong currents, and rapid changes through both Cretaceous and Tertiary times.

(4) In early Miocene time intrusion of andesite laccoliths, principally into the Carboniferous limestone, but also into the overlying Cretaceous, accompanied by tilting of all the formations away from the laccoliths, steeply near the laccoliths, less steeply farther away. Limestone and sandstone were metamorphosed near the contact.

(5) Fissuring and faulting caused by cooling of laccoliths.

(6) Immediate advent of ore-depositing solutions through fissures in the andesite, depositing iron ore in the andesite fissures and in the adjacent limestone and affecting other alterations.

(7) Erosion, exposing the laccoliths and rings of sediments and ores around them.

(8) Extrusion of late Miocene lavas over the entire area, except possibly some of the higher peaks of the exposed laccoliths, effecting a secondary concentration of the ores and further altering the underlying rocks.

(9) Further faulting.

(10) Vigorous erosion, reexhuming the andesite cores and developing the Pleistocene conglomerate and the Pleistocene and Recent mantle of stream, lake, and other alluvial deposits.

DEVELOPMENT OF TOPOGRAPHY.

The outlines of the andesite cores at their contacts with the sediments are determined largely by their original forms. Their surface forms are in general those of mature topography. While nearly all the surfaces are smooth and rounded, differential erosion along vertical and concentric fissures has developed most irregular and fantastic forms. (See Pl. VIII, *A*, *B*.)

Erosion of the sediments has developed monoclinal ridges with their steeper edges toward the andesite and dip slopes away from it. Especially conspicuous are the ridges of pink and red conglomerates, sandstones, and limestones of the Eocene, which may be seen for many miles about from points on the laccoliths. In general the relief and slopes of the sediments are low.

The horizontal lava flows, overlying the sedimentary deposits and fringing the outer edge of the sedimentary area, form conspicuous foothills or mountains, only a little lower than the laccoliths themselves. Erosion has worked down along joints and faults, developing a mesa type of topography, and in detail often presenting the same erosion forms as the laccolithic andesite (Pl. VIII, *C*).

In a broad way the Carboniferous, Cretaceous, and Eocene sediments occupy a valley between mountains formed by the andesite laccoliths and the flat-topped lava hills.

Faults considerably modify the general relations thus outlined. Fault scarps are common, some of them ranging up to 1,000 feet in height, but as a rule erosion has partially or completely masked them. Erosion has frequently worked down along fault planes, with the result that many depressions mark faults. Instances of drainage along fault lines are seen in both branches of the Queatchupah and in several minor valleys to the southeast, in Stoddard Canyon, southeast and northeast of Joel Springs Canyon, around Antelope Range, Antelope Springs, and westward, in the Eightmile Hills, and west of the northern part of The Three Peaks. Instances of canyons following joints were seen abundantly in the western part of The Three Peaks, where there are a number of short parallel canyons following a nearly east-west slicing of the andesite.

The lower slopes in general are grade slopes in the heavy mantle of débris resulting from rapid erosion and inadequate transportation. On the desert this material is spread out in broad, low fans. The grade slopes are notched by sharp ravines and canyons.

The principal events in the development of the present topography have been: (1) Intrusion of laccoliths in early Miocene time, followed by faulting and erosion, exposing the laccoliths and surrounding belts of sediments and developing in the laccolith cores a mature type of topography; (2) extrusion of late Miocene lavas, followed by fault-
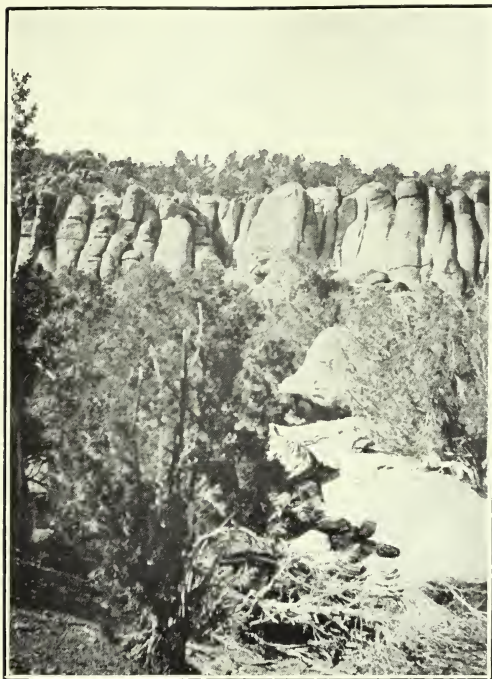
A EROSION FORMS OF THE LATEST TRACHYTE, SWETT
HILLS.
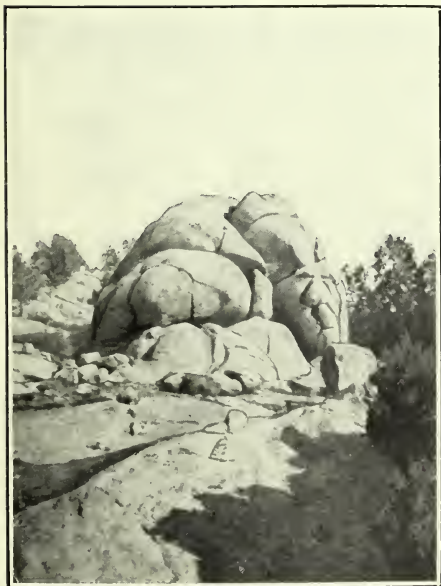
B. EROSION FORMS OF LACCOLITHIC ANDESITE
THE THREE PEAKS.
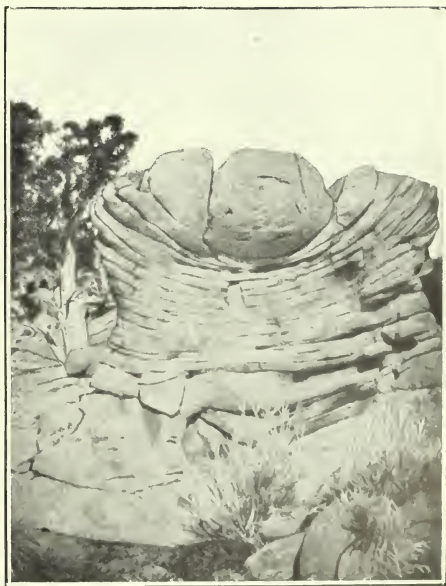
C. CONCRETIONARY EROSION OF THE LACCO-
LITHIC ANDESITE. THE THREE PEAKS.

ing and by erosional exhumation of the laccolith cores and surrounding sediments, so far as these have been covered by the lavas, and developing a mature type of topography in the lavas themselves; (3) Hurricane faulting to the east, causing a slight renewal of activity, exhibited in the sharp canyons and steep sides of some of the lava hills.

There have thus apparently been three partial erosion cycles, the second one now shown chiefly by the flat tops of mesas like the Harmony Mountains and the third by the sharp ravines and canyons. But it is doubtful if the term cycle should be used here, for it implies uplift and renewal of activity of streams, the evidence for which is not satisfactory. There has been an interruption of erosion by the extrusion of the lavas, but the only evidence which can be cited for uplift and renewal are the sharp ravines and canyons; and it may be observed that both these and the grade slopes are being developed at the present time. The rapid development and modification of the grade slopes has already been referred to. But the rapid cutting of the ravines and canyons in these same grade slopes is no less striking. There is an alternate leveling up of the deep ravines to the grade slopes and the development of new ravines in periods of alternating high and low precipitation.

Huntington and Goldthwait, in their excellent paper on the Toquerville area, cut by the Hurricane fault to the southeast of the Iron Springs district, work out two cycles of erosion similar to the second and third here presented. Their first cycle occurred after the extrusion of trachyte, rhyolite, and andesite and subsequent faulting, and corresponds to the second cycle in the Iron Springs district. There appears to be no evidence in the Toquerville district for the prelava and postintrusion cycle of the Iron Springs district. The second cycle of Huntington and Goldthwait occurred after the basalt flows and the later Hurricane faulting. For this cycle there is scant evidence in the Iron Springs district. They cite the Pine Valley Mountains and similar structures of the Iron Springs district and southwest as an expression of the mature topography of their first cycle, and correlate it with certain remnants on the High Plateaus, which were then very much lower than at present, the Pine Valley Mountains being the dominant topographic feature. During the Hurricane faulting the High Plateaus were raised, and renewed erosion cut deep vertical-walled canyons into them, which are the present expression of the second cycle. This faulting produced very little difference of elevation west of the present Hurricane scarp, hence this region, including the Iron Springs district, shows mainly the old mature topography. There are, however, small canyons in the Iron Springs district which may show a renewal of activity and may be comparable to the steep-sided canyons of the High Plateaus.

CHAPTER III.

SEDIMENTARY FORMATIONS.

CARBONIFEROUS SYSTEM.

HOMESTAKE LIMESTONE.

DISTRIBUTION.

The Homestake limestone outcrops in or around the andesite laccolith areas and immediately in contact with the andesite.

West of The Three Peaks laccolith it is exposed in a band extending from the northern boundary of the district southwestward for about 3 miles and then southeastward to a point northeast of Iron Springs, except where, by faulting, the Cretaceous formations are brought into contact with the andesite for a distance of about a mile.

Northeast of the Granite Mountain laccolith a band of Homestake limestone is exposed for about 2 miles. Both ends of this band are overlapped by the Pinto sandstone, which here again comes in contact with the andesite. At the Desert Mound, southwest of Granite Mountain, the Homestake limestone again appears. It is cut off by a fault on the west and disappears under the lake and stream deposits on the east.

The Iron Mountain laccolith is bordered by the Homestake limestone on its northeast, east, south, and southwest sides, with a few interruptions due to faulting or covering by surface deposits. Southwest of the laccolith the limestone has considerable width, owing to the fact that the surface of the supporting laccolith is nearly horizontal here, as shown by the tongue of andesite extending westward from the main mass and by the few andesite outliers in the Homestake limestone. On the west and north sides of the Iron Mountain laccolith, as in Granite Mountain, the Homestake limestone is not exposed, the Cretaceous sandstones lapping against the laccolith.

A patch of Homestake limestone is present in the Comstock iron deposit in the Cretaceous area southwest of the Homestake mine; others are scattered irregularly within the area of the Iron Mountain laccolith.

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CHARACTER.

The Homestake limestone is a dark bluish-gray limestone of a dense texture, with uniform characteristics throughout its entire extent, except near the laccolith contact. Under the microscope the limestone appears to be made up of exceedingly minute grains of calcite with scattered grains of pyrite, magnetite, and chert.

The bedding of the Homestake limestone is very indefinite and is easily confused with secondary fracturing. Where it is well defined the limestone is generally thin bedded.

CONTACT METAMORPHISM OF LIMESTONE BY ANDESITE LACCOLITHS.

Phases of alteration.—The limestone adjacent to the andesite has been locally replaced by iron ore and has been generally vitrified, silicated, and kaolinized in a band usually not more than 60 feet wide along the erosion surface, although locally it may be a few hundred yards wide where the erosion surface is nearly parallel to the limestone-andesite contact. Locally either or both contact phases are absent.

The altered limestone is a grayish, yellow, or greenish, fine-grained, argillaceous-looking rock. Near the contact it is soft, and farther away it is hard and fractured into small irregular blocks. The principal minerals are albite, kaolin, actinolite, diopside, quartz, orthoclase, serpentine, phlogopite, andradite, iron ores, osteolite, andalusite, wollastonite, calcite, etc., varying greatly in proportion in different places, but usually occurring in quantity in the order named. They are found in veins, in breccias, and disseminated through the rock. In addition there are local residues of a glassy base. The albite is probably not as abundant as here indicated, but very likely includes other sodium silicates which have not been detected. The glass can be distinguished only with difficulty from opal and other isotropic minerals. Its index of refraction was determined as 1.56 by means of the Becke method used in conjunction with liquids of known index of refraction. This distinguishes it from opal (1.45) and other isotropic minerals which might be found in contact-metamorphic limestones.

Another phase is coarsely crystallized limonite-stained marble, in some places found in a narrow belt between the andesite and the normal silicated contact phase and elsewhere outside of the normal phase or associated with the ore. It is thought possible that this limonitic marble is a later vein material, filling openings along the contact left by the cooling and crystallization of the intrusive and intruded masses.

Analyses of various phases of the Homestake limestone are given on the following pages.

Analyses of Homestake limestone.

UNALTERED HOMESTAKE LIMESTONE.

	A.[a]	B.	C.	D.	E.	F.	G.
SiO_2	8.08	6.90	3.78	....	....	16.48	3.12
Al_2O_3	1.95	1.03	1.14	....	....	1.78	.71
Fe_2O_3	.87	1.04	1.80	....	....	....	....
Fe	....	....	....	0.28	0.46	.95	1.12
FeO	.06	.75	....	....	....	....	....
MgO	2.86	4.52	.64	1.78	2.67	....	....
CaO	46.67	47.15	50.39	50.77	49.46	....	....
Na_2O	.13	.13	....	....	....	....	....
K_2O	.77	.93	....	....	....	....	....
H_2O+	1.01	1.04	....	....	....	....	....
P_2O_5	.05	.04	.042	.03	.03	.037	.023
CO_2	37.60	36.42	39.92	....	....	....	....
BaO	None.	None.	....	....	....	....	....
	100.05	99.95	97.71	....	....	....	....

[a] These letters are used throughout the discussion of the Homestake limestone in referring to the specimens and their analyses.

ALTERED HOMESTAKE LIMESTONE NEAR ANDESITE CONTACT, AND DIOPSIDE.

	Normal contact phase.			Exceptional contact phases.					Diopside.
	H.	I.	J.	K.	L.	M.	N.	O.	P.
SiO_2	50.73	52.00	57.05	11.31	2.38	4.08	45.05	75.16	51.72
Al_2O_3	14.63	9.32	9.86	1.64	2.02	1.05	1.95	2.39	1.99
Fe_2O_3	11.51	5.08	3.10	4.75	6.20	....	18.22	....	3.30
Fe	....	....	....	....	....	2.41	....	1.97	....
FeO	1.13	2.41	1.80	2.55	None.	....	2.38	....	4.95
MgO	6.36	9.40	8.16	.41	.45	....	.35	....	15.08
CaO	1.24	14.47	8.61	42.57	48.80	....	14.99	....	23.22
Na_2O	2.02	1.94	4.30	.12	....	....	1.65	....	.05
K_2O	4.24	1.41	1.56	.25	....	....	.72	....	.06
H_2O+	7.03	3.30	3.89	1.43	2.07	....	4.09	....	.50
P_2O_5	.32	.12	.13	2.36	.03	.02	.64	.074	....
CO_2	.21	.63	1.74	32.30	....	....	9.34	....	....
BaO	.01	None.	None.	.02	None.	....	.10	....	....
MnO	....	....	....	....	....	....	....	....	.04
	99.43	100.08	100.20	99.71	....	....	99.49	....	100.91

A. Specimen No. 46319. Unaltered blue limestone west of Three Peaks. Analysis by R. D. Hall, University of Wisconsin.

B. Specimen No. 46375. Unaltered blue limestone from Desert Mound. Analysis by R. D. Hall, University of Wisconsin.

C. Unaltered limestone from Iron Mountain. Analysis by Fred Lerch, Biwabik, Minn.

D. Specimen No. 46123. Unaltered blue limestone. Partial analysis by George Steiger, U. S. Geol. Survey.

E. Specimen No. 46121. Unaltered blue limestone. Partial analysis by George Steiger, U. S. Geol. Survey.

F. Specimen No. 46319A. White limestone west of Three Peaks. Analysis by Fred Lerch, Biwabik, Minn.

G. Specimen No. 46325. White limestone west of Three Peaks. Analysis by Fred Lerch, Biwabik Minn.

H. Specimen No. 46338. Altered limestone between ore and andesite on Lindsay Hill. Analysis by R. D. Hall, University of Wisconsin.

I. Specimen No. 46349. Altered limestone between ore and unaltered blue limestone at Desert Mound. Analysis by R. D. Hall, University of Wisconsin.

J. Specimen No. 46376. Altered limestone between ore and andesite at Desert Mound. Analysis by R. D. Hall, University of Wisconsin.

K. Specimen No. 46437. Recrystallized limestone in vein a few feet thick at andesite contact, showing partial replacement by iron and silica. From Boston claim. Analysis by R. D. Hall, University of Wisconsin.

L. Specimen No. 46320. Recrystallized limestone impregnated with limonite, in vein near andesite-limestone contact west of Three Peaks. Analysis by R. D. Hall, University of Wisconsin.

M. Specimen No. 46321. Same as L. Analysis by Fred Lerch, Biwabik, Minn.

N. Specimen No. 46438. Same as K, showing a further stage in replacement by iron and silica. Analysis by R. D. Hall, University of Wisconsin.

O. Specimen No. 46326. Siliceous platy alteration phase of limestone west of Three Peaks. Analysis by Fred Lerch, Biwabik, Minn.

P. Specimen No. 46478. Diopside from long tunnel on Dear claim. Analysis by R. D. Hall, University of Wisconsin.

A
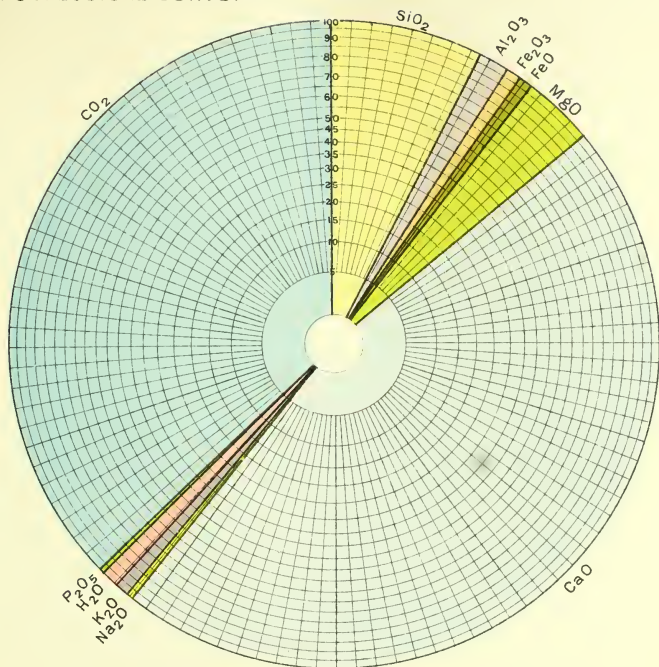
GRAPHIC REPRESENTATION OF COMPOSITION OF FRESH LIMESTONE

B
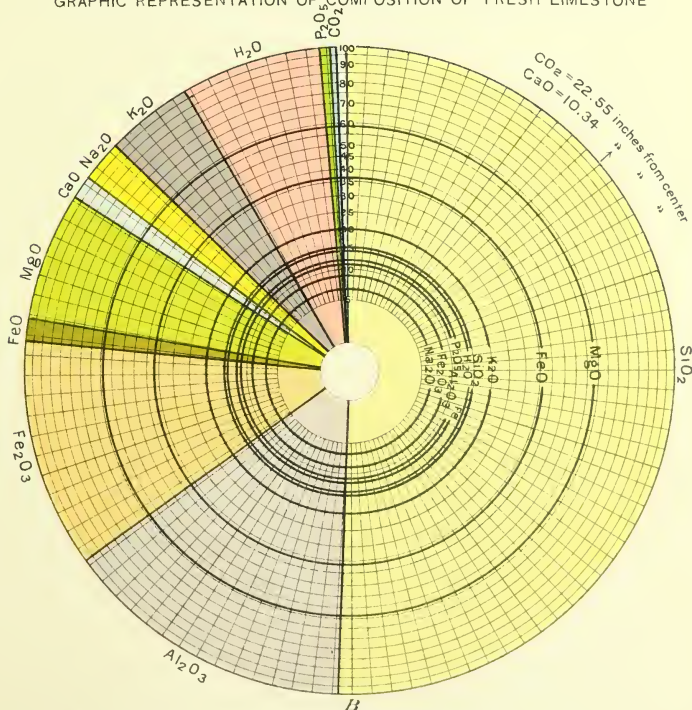
GRAPHIC COMPARISON OF COMPOSITION OF ALTERED LIMESTONE, ANALYSIS "H," WITH FRESH LIMESTONE (AVERAGE OF ANALYSES "A" AND "B")

A
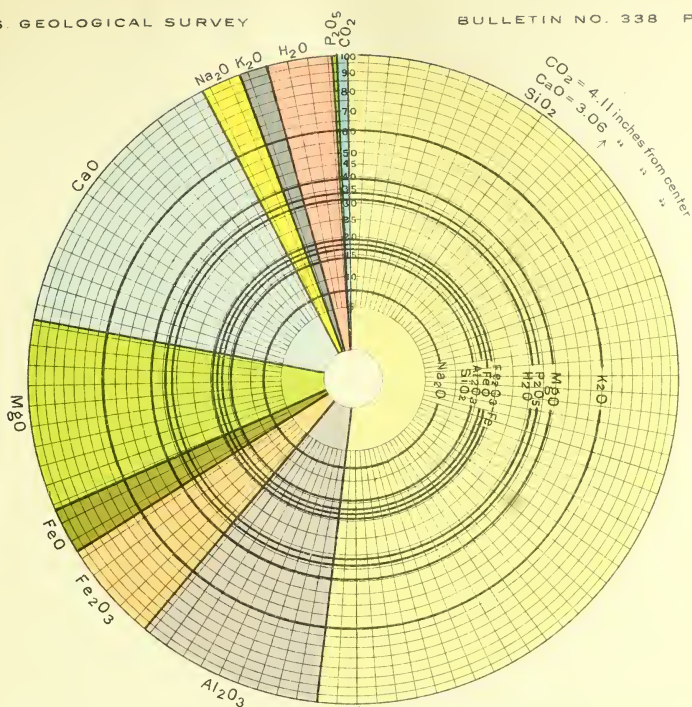
GRAPHIC COMPARISON OF COMPOSITION OF ALTERED LIMESTONE, ANALYSIS "I,"
WITH FRESH LIMESTONE

B
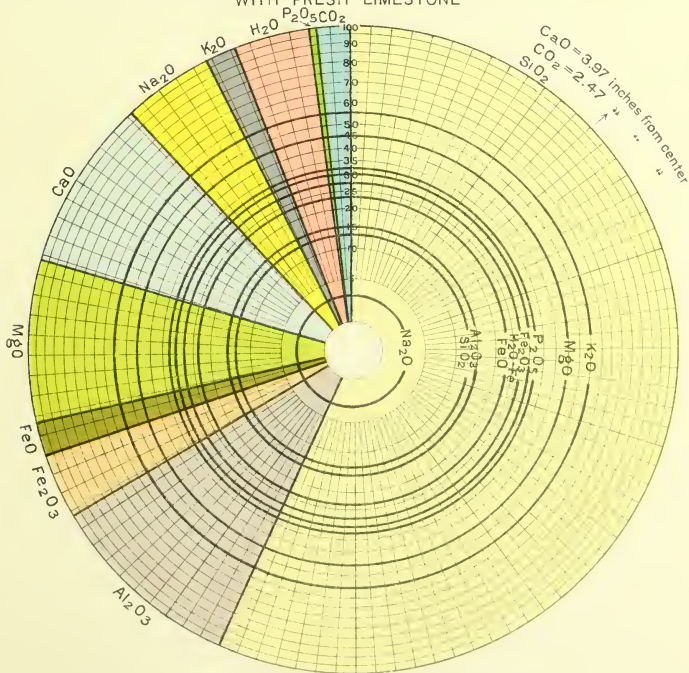
GRAPHIC COMPARISON OF COMPOSITION OF ALTERED LIMESTONE, ANALYSIS "J,"
WITH FRESH LIMESTONE

Mineralogical composition of fresh and altered Homestake limestones, calculated from chemical composition.

Mineral.	Fresh limestones.		Altered limestones.					Average of common type of altered limestone (H, I, J).
	A.	B.	H.[a]	I.	J.	K.	N.	
Calcite	78.30	72.40	0.50	1.40	3.90	70.80	21.10	1.93
Kaolin	4.90	2.58	24.77	11.61	3.09	3.10		13.16
Chert	2.64		18.78	1.50	6.30	7.92	34.14	8.86
Actinolite				15.55	19.00			11.52
Diopside			2.16	20.52	4.32	.86	1.94	9.02
Phlogopite			15.57					5.19
Serpentine			5.24	4.97	6.76			5.66
Andradite				11.20	3.14			4.78
Magnesite	5.96	8.65				.50		
Wollastonite	6.03	9.86		4.76	3.13		5.10	2.63
Albite			16.77	16.24	36.15	1.05	6.81	23.02
Orthoclase				8.34	8.89	1.11	3.89	5.74
Limonite	1.12	.56	3.74	1.31	2.62	2.62	3.93	2.55
Magnetite		.69	3.48			3.48	7.66	1.16
Hematite			5.92				9.60	2.03
Enstatite		1.00						
Apatite			.62	.31	.31	4.96	1.24	.41
Pyrite	.12	.84						
Water	.16	.59	1.54	.81	2.21	.59	3.53	1.52
Siderite						2.32		
Witherite							.20	
	99.23	97.17	99.09	98.52	99.82	99.31	99.14	99.18

[a] Contains glass which has been calculated in terms of minerals.

Introduction of ore.—The introduction of ore took place after the development of the silicated contact phase, as is demonstrated by its occurrence in fissures that intersect this phase. The silicated contact phase is found also along parts of the contact where ore is absent. The introduction of ore-bearing solutions effected further metamorphism of the limestone of approximately the same sort, nearly all of the minerals found at the barren contacts being duplicated within and adjacent to the ore itself. (See analyses above.) Apatite, amphibole, biotite, pyrite, and garnet are more abundant in association with the ores than elsewhere in the contact phase, while albite and orthoclase appear in the contact phase and not in the ores. Beyond this it has not been found possible to separate the metamorphic effect of the ore-bearing solutions, aside from its deposition of ore, from the earlier contact effect of the andesite, although it is thought likely that additional careful field work with this object in view might lead to the discovery of further criteria for their separation. The replacement of the limestone by ore is discussed in connection with the origin of the ore (pp. 75–79).

Normal contact phase.—The following paragraphs are devoted to the silicated contact phase, which is described as a unit, without regard to the extent to which it has been developed under the influence of the first contact of the andesite or under the influence of later ore-bearing solutions, although the former is unquestionably dominant.

Analyses of fresh and altered rocks show clearly the net results of the alteration, but they tell little of the extent to which the transfers of materials have been additions or subtractions, unless it is assumed that one substance has remained constant during the change. A variety of inferences are therefore possible, depending upon which substance is selected as a basis against which to measure the changes of the other constituents of the rock. Some substances are easily eliminated as possible constants; for instance, calcium carbonate, in the alteration of a limestone to a silicated rock; for if this material were assumed to remain constant in amount during the alteration, it would require so large an addition of other substances to develop the proportions in the altered rock that the volume would be increased beyond the possibilities of the situation, even allowing for increased density. But other constituents are not so satisfactorily eliminated by such reasoning, and there arises uncertainty and error in the selection from among the various possibilities of the particular substance to serve as a basis of comparison of two analyses. If each substance in turn is considered as constant, the work of calculation becomes tedious and the probabilities of the situation are not easily discerned in the mass of figures and tables obtained.

To meet these difficulties in inferring from analyses the real nature of the rock alterations, the writers present graphic comparisons of the analyses (Pls. IX–XII, A), from which it is possible, by assumptions of constancy of any constituent during alteration, to read the percentage gains and losses of other constituents as a result of alteration, and, what is more important, to see at a glance what the probable constants are, without losing sight of the other possibilities.

In the accompanying diagrams a circle with $1\frac{3}{4}$-inch radius is divided by radii into 100 sectors, each sector therefore representing 1 per cent of the total area of the circle. It is also divided into a series of annuli by concentric circles so spaced [a] that the area of each annulus is equal to 5 per cent of the total area of the circle. The subdivisions of the area, bounded by the sectorial radii and the concentric circles, are therefore equivalent areas and each represents 0.05 per cent of the total area of the circle.

On the base diagram thus constructed, in Pl. IX, B, for example, the areas of sectors shown in different colors represent percentage weights of constituents of the altered limestone. Thus silica (analysis II) constitutes about 50 per cent of the altered rock. Of the fresh rock silica (average of analyses A and B) makes up about 7.5 per cent. The ratio of the two is 0.15, and hence the silica of the fresh rock is 15 per cent of the silica of the altered rock. This is indicated on the diagram by the area of the silica sector cut off by the black circle

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[a] The area varies as the square of the radius.

marked "SiO$_2$" (which may be called the "silica circle"). This circle is drawn with such a radius that its area is 15 per cent of the base circle, and it follows that the portion of the silica sector included is 15 per cent of the whole silica sector.

In the same way the alumina (analysis H) makes up nearly 15 per cent of the altered rock and (average of analyses A and B) about 1.5 per cent of the fresh rock; that is, the alumina in the fresh rock is 10 per cent of that in the altered rock. In the diagram, therefore, the alumina in the altered rock is represented by a sector occupying 15 per cent of the area of the base circle, and to show the relations of that in the fresh rock a circle is drawn so as to include 10 per cent of the total area and consequently 10 per cent of the area of the alumina sector. In a similar manner the relations of the various other constituents in the altered and fresh rock are shown.

The important feature of the diagram is the fact that starting from the silica circle, or the circle representing any other constituent assumed to have remained constant, the actual gains or losses of other constituents may be obtained from the diagram by a simple subtraction.

If silica be assumed constant, the amount of magnesia, for instance, necessary to make up the percentage of magnesia in the altered rock is measured by the area of the magnesia sector included in the silica circle. But on the magnesia sector the magnesia in the original rock is represented by the area of the magnesia sector within the magnesia circle. There are indicated, therefore, both the amount of magnesia required, on the assumption that the silica is constant, and the amount of magnesia actually present in the original rock, which in this case is more than is necessary to meet the required proportion in the altered rock. Magnesia has therefore been lost by an amount measured by the area of the annulus between the silica and the magnesia circles as they cross the magnesia sector. If soda be assumed constant, all constituents other than soda have been lost in amounts measured by the difference between the area of their sectors inside their circles and that inside of the soda circle, which may be taken from radial scale. From the numbers thus obtained the percentage change is readily calculated. If, at the other extreme, calcium carbonate has remained constant, there has been gain of all other constituents, their circles all being smaller than the carbonate circle. Complete or nearly complete removal of a constituent is represented by an arrow.

In general it will be noted that the constituents whose circles lie outside of the circle of the constituent assumed as constant have suffered loss, while those whose circles lie inside have gained. The amount of gain or loss is proportional to the difference between the areas controlled by the superimposed polar coordinates of the several

constituents. In practice a comparison of size of circles gives the gains or losses of any constituent against any other constituent, without elaborate calculation.

Where several circles are of nearly the same size, this means that the constituents represented have maintained their mutual proportions during the alteration, and such maintenance of mutual proportions becomes presumptive evidence that the group has remained essentially constant during the alteration and that the change in composition has been effected by gain or loss of other constituents. It may be sufficient, therefore, instead of regarding each of the constituents as possible constants, to consider only those whose ratio circles lie near together. Thus in the present illustration the close grouping of the circles representing silica, alumina, and iron suggests that the constant is to be looked for in this group, and the conclusions then drawn as to the transfers of materials are probably on safer ground than they would be from assumption of constancy of one constituent, without taking into account the additional evidence afforded by the persistence of mutual relations within certain groups. The diagrams have been found also to have unlooked-for value in the recording and comparisons of long series of analyses, affording means for comparison of composites of series of similar alterations, which would involve tedious calculations by ordinary mathematics.

To avoid confusion, it may be stated that the diagrams represent weight alone, and that the gains and losses of weights mean nothing as to change in volume, unless the density is taken into account, as it may be on the same diagrams by a simple graphic device.

The attempt has been made to make the above explanation fairly brief and nontechnical, and not to emphasize the mathematical steps of the process, in order to bring to the reader the real simplicity and usefulness of the diagrams. They are easily grasped and understood by the student when explained empirically, but when the various steps in the construction of the diagrams are mathematically demonstrated the explanation becomes formidable to the nonmathematical reader. For the sake of those requiring more technical explanation the following supplementary account is given:

On the base figure constructed as stated above the percentage composition of any two rocks may be readily represented. For example, in Pl. IX, B, if the area of the whole circle be taken to represent a 100-unit mass of the altered rock (analysis H), then the proportional masses or percentages of the several constituents are shown by the areas of the variously colored sectors. Since the area of any sector varies as the arc which subtends it, the size of the sector of any constituent is readily ascertained by laying off an arc proportionate to the percentage of that constituent. The proportional masses or percentages of the several constituents in a 100-unit
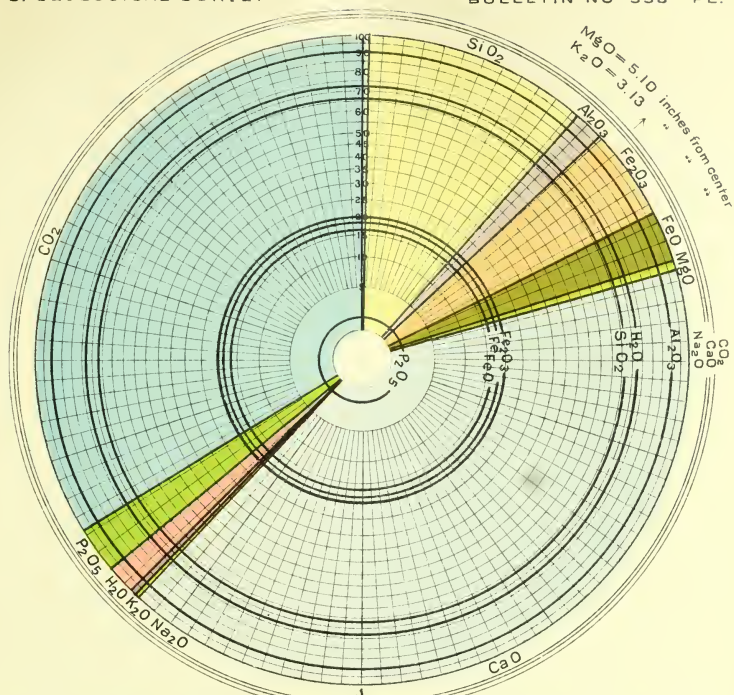
GRAPHIC COMPARISON OF COMPOSITION OF ALTERED LIMESTONE, ANALYSIS "K,"
WITH FRESH LIMESTONE
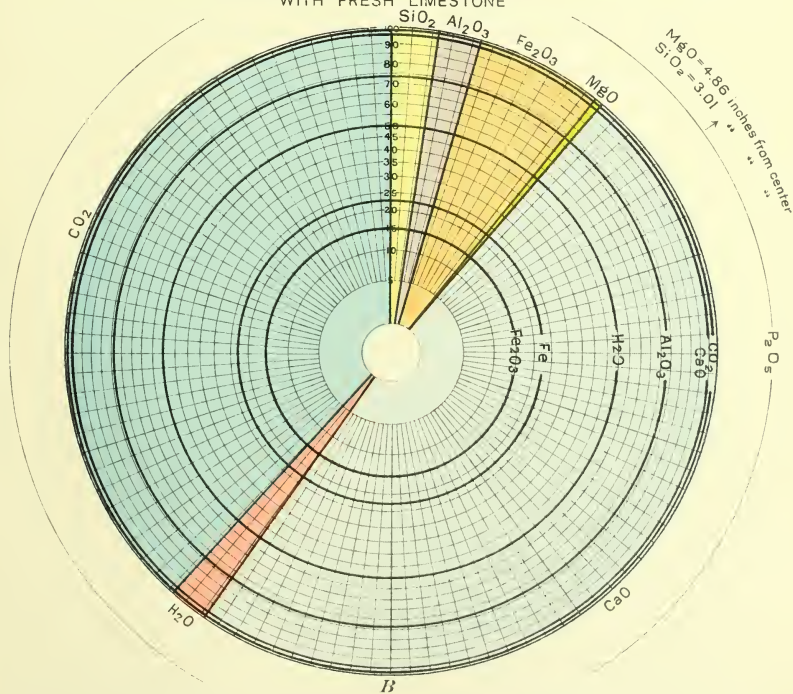
GRAPHIC COMPARISON OF COMPOSITION OF ALTERED LIMESTONE, ANALYSIS "L,"
WITH FRESH LIMESTONE
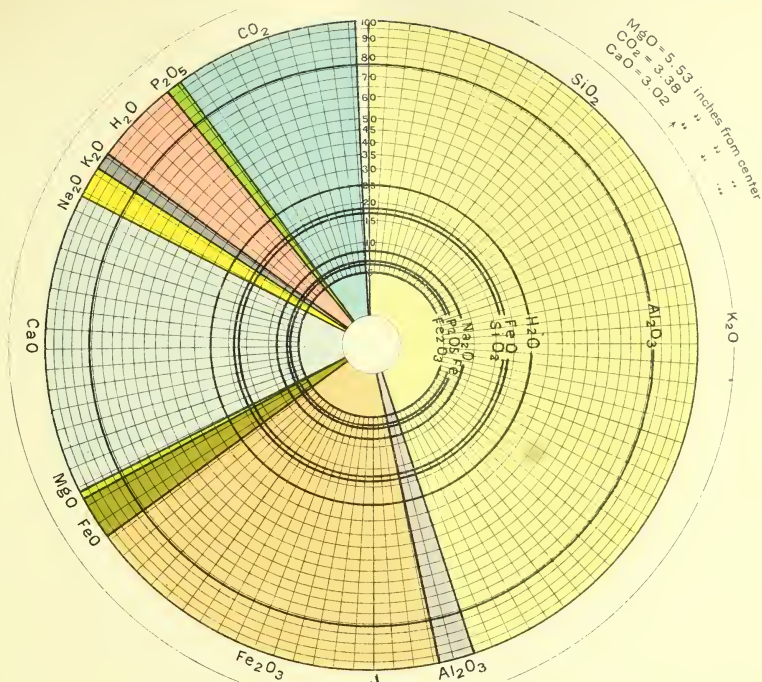
GRAPHIC COMPARISON OF COMPOSITION OF ALTERED LIMESTONE, ANALYSIS "N," WITH FRESH LIMESTONE
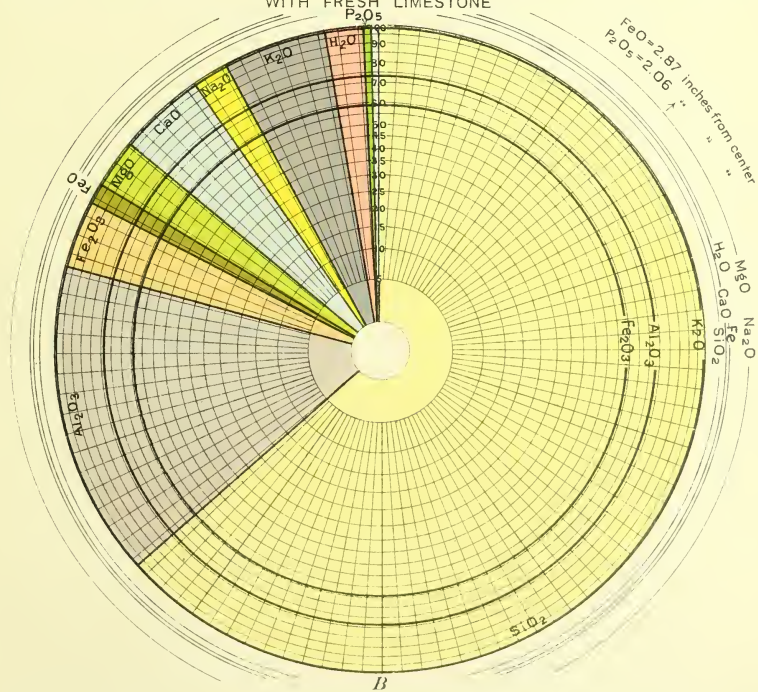
GRAPHIC COMPARISON OF COMPOSITION OF WEATHERED ANDESITE, ANALYSIS "B," WITH FRESH ANDESITE

mass of the original rock (average of analyses A and B) are shown by appropriate areas on the sectors already determined from the analysis of the altered rock. The construction for any constituent is effected by using the ratio of the percentages of this constituent in the original and in the altered rock, as follows: Lay off the determined ratio on the radial percentage scale of the base figure, and through the point thus formed draw a circle concentric with the base circle. The portion of the sector of the chosen constituent lying within the circle thus drawn represents the amount of this constituent in a 100-unit mass of the original rock. In order to make this relation clear, let us consider magnesia as an example. Since the altered rock (analysis H) contains 6.3 per cent of magnesia, take an arc of the base circle equal to 6.3 of the unit divisions. The area of the sector subtended by this arc is 6.3 per cent of the area of the base circle, so that the sector represents the number of unit masses of magnesia present in a 100-unit mass of the altered rock, or, what is the same thing, it represents the percentage of magnesia in the rock. Now, the original rock (analyses A and B) contains 3.7 per cent magnesia and the altered rock (analysis H) 6.3 per cent. The ratio of these numbers, 0.59, expresses the fact that the magnesia in a 100-unit mass of the original rock is only 59 per cent of that in an equal mass of the altered rock. Now, 59 per cent of the base circle and also 59 per cent of any sector lies within the circle drawn through point 59 on the radial scale, so that the area common to the magnesia sector and the 59 per cent circle (which may be called the magnesia circle) is 59 per cent of 6.3, or 3.7, which is the percentage of magnesia which it is desired to represent.

The proportional masses or percentages of the various constituents in both rocks being represented in the manner indicated, the completed diagram furnishes all the factors necessary for making any desired comparisons when it is assumed that the amount of any chosen constituent has remained unchanged.

An example will serve to indicate the principle on which the comparisons are made. The rock of analysis H has been derived by alteration from the rock of analyses A and B. Both analyses are represented on Pl. IX, B. Assume silica to have remained constant, what has been the gain or loss of magnesia during alteration? Apart from the diagram the change in magnesia may be calculated from the data given in the analyses in the following manner: A 100-unit mass of the original rock contains 7.5 units of silica, while a 100-unit mass of the altered rock contains 50 units of the same constituent. Therefore 15 units of the altered rock contain the same amount of silica as a 100-unit mass of the original rock. Now, 15 units of the altered rock contain $0.15 \times 6.3 = 0.95$ unit of magnesia. Evidently there has been a loss, since in 100 units of the original rock there are

available 3.7 units of magnesia. Therefore, $3.7 - 0.95 = 2.7$ represents the number of units of magnesia lost during the alteration, if silica has remained unchanged, and $\frac{2.7}{3.7} = 0.75$, or 75 per cent, the ratio of loss. The number of necessary operations in this calculation may be reduced by using in the place of 3.7 the equivalent expression 0.59×6.3. Then the formula for the ratio of loss becomes $\frac{(0.59 \times 6.3) - (0.15 \times 6.3)}{0.59 \times 6.3}$, or, eliminating common factors, $\frac{0.59 - 0.15}{0.59} = \frac{0.44}{0.59}$, or 0.75, as before.

Now, by construction, the diagram gives the numbers 59 and 15, which by substraction gives 44; then $\frac{44}{59}$ gives 0.75 as above; or, converting this decimal fraction into percentage gives 75 per cent as the loss of magnesia during the alteration.

From the above the following rule is derived: To determine the percentage gain or loss of any constituent during alteration, any other constituent being assumed as constant, read on the radial scale the difference between the ratios expressed by the constant-constituent circle and the variable-constituent circle, and divide this by the ratio expressed by the variable-constituent circle. The result will be the percentage gain or loss of the variable constituent. Evidently gains will be shown by ratios greater than unity and losses by ratios less than unity.

We may take up now the specific inferences which may be drawn from the diagrams under discussion.

If calcium has remained constant there has been a great increase of all the other constituents and an increase of weight of the rock. If potassa be assumed constant there has been a considerable gain of all other constituents, except lime, in analyses I and J, and a gain of all other constituents, except magnesia and lime, in analysis H. If magnesia has remained constant there has been a loss in potassa and lime and a gain in other constituents in I and J, and a gain of all constituents except lime in II.

If silica and alumina remain constant this has involved a loss of all constituents except soda. The silica and alumina constants are nearly the same throughout. Soda is the only substance which, considered constant, shows a loss of all other constituents.

Of these various assumptions the constancy of alumina and silica seems to be the most probable. The conspicuous feature in the alteration is the *relative* increase of silica and alumina at the expense of calcium carbonate. This means either (1) that silica and alumina have been introduced from without to replace the calcite, in which case there may not have been any considerable change in the volume

of the rock during alteration; or (2) that calcite has been taken out of the fresh limestone, leaving the silica and alumina in larger proportion, in which case the weight and, as will be shown later, the volume has considerably decreased; or (3) some combination of these two methods has accomplished the same result. Alternative 2 is favored by the fact that, while the alumina has gained slightly in percentage on the silica, the ratio of the two substances in the fresh and altered rocks remains substantially the same, in the fresh rocks average alumina standing to silica as 19 to 100, and in the altered rocks as 21 to 100. (See analyses, pp. 26–27, and Pl. X.) The near accordance of the alumina and silica circles in Pl. X brings out well the uniformity of the ratio. If silica and alumina have been added from without, it is a remarkable coincidence that they should have been added in so nearly the same proportion as in the fresh rock, especially when it is remembered that their proportion in the fresh limestone is not determined by silicate ratios but rather by the abundance of chert.

On the assumption that alumina remains constant, it will be noted that the greatest percentage lost is calcium, next magnesia, then potassa, and then silica, which is the order of solubility of these substances in weathering. The only exception is soda, which without much question has been introduced into the contact phase. It will be noted further that the composition of the altered rock is essentially that of a calcareous residual clay.

Comparison of average fresh Homestake limestone with normal contact phases, with alumina (Al_2O_3) assumed to be constant.

	A, B.	H.		I.		J.		H, I, J.	
	Average, fresh.	Altered.	Variation from A, B.	Altered.	Variation from A, B.	Altered.	Variation from A, B.	Average.	Variation from A, B.
SiO_2........	7.49	5.168	− 2.322	8.313	+ 0.823	8.62	+ 1.13	7.367	− 0.123
Al_2O_3......	1.49	1.49	0.00	1.49	0.00	1.49	0.00	1.49	0.00
Fe_2O_3.....	.95	1.172	+ .222	.812	− .138	.468	− .482	.817	− .133
FeO.......	.41	.115	− .285	.385	− .025	.271	− .139	.290	− .120
MgO......	3.69	.648	− 3.042	1.502	− 2.088	1.233	− 2.467	1.127	− 2.563
CaO.......	46.91	.126	−46.784	2.313	−44.597	1.301	−45.609	1.243	−45.665
Na_2O......	.13	.206	+ .076	.310	+ .180	.649	+ .519	.388	+ .258
K_2O.......	.85	.432	− .418	.225	− .625	.236	− .614	.298	− .414
H_2O+.....	1.03	.716	− .314	.527	− .503	.588	− .442	.610	− .419
P_2O_5......	.04	.032	− .008	.019	− .101	.019	− .021	.023	− .043
CO_2.......	37.01	.021	−36.989	.100	−36.910	.263	−36.747	.128	−36.882
	100.00	10.126	89.864	15.996	83.984	15.138	84.872	86.104	−13.791

Exceptional contact phases.—These phases represent introduction of calcite, iron, and silica. Analysis L is of an iron-stained marble in a vein. Probably all of the constituents are secondary, but if the alumina or silica is the same as in the fresh limestone, there has been a considerable introduction of iron and a slight loss of calcite and soda, or if alumina has remained constant there has been also a gain

of silica. * Sample N is a contact phase of the limestone in which there has been conspicuous introduction of soda, silica, water, and iron and loss of calcite and potassa. K is an intermediate stage between the fresh limestone and N.

General result of alteration.—It is concluded that in general there has been large loss of material from the limestones at the contact without conspicuous introduction of new material except soda, but that exceptional phases show clearly the introduction of silica and iron. Both normal and exceptional phases of the contact rocks are cut by later veins of calcite and iron ore, with associated minerals similar to those of the limestone contact. (See p. 85.)

Changes in density and volume during contact metamorphism.— Specific-gravity determinations of the fresh and contact phases of the Homestake limestone are as follows:

Specific gravities of fresh and contact phases of Homestake limestone.

	Fresh limestone.		Contact phase.				Average of fresh limestones.	Average of all contact phases.
	A.	B.	H.	I.	J.	Average of 5 specimens from contact, including H, I, J, and L.		
Specific gravity determined from mineral calculations	2.739	2.775	2.74	2.93	2.73	....	2.76	2.86
Specific gravity determined from hand specimens	2.705	2.706	2.22	2.59	2.57	2.56	2.70	2.56
Specific gravity determined from powdered specimens	......	......	2.20	2.92	2.68	....	....	2.60
Pore space calculated from specific gravities of hand specimens and powdered specimens	......	......	......	10.2	4.1	....	2.2	7.1

The difference between the gravity determined in the hand specimen and that in the crushed specimen measures the pore space. The fresh limestone when powdered is slightly soluble in water, vitiating gravity determinations. In this case the difference between calculated and measured gravities measures the pore space, for there is little chance for error in the computed gravity. The only altered rock not having pore space, H, is made up largely of glass. Taking the glass into account, there has been little average increase of pore space in the contact rocks as a group, if the analyses represent proper proportions of contact phases. Leaving this out of consideration, the pore space at the contact has increased slightly, from 4 per cent to 10 per cent.

The calculated specific gravities correspond fairly well with those determined from the powdered specimens, affording a check on the computation of the mineral composition from the chemical analyses. Sample H is again an exception because the contained glass has a specific gravity considerably lower than that computed from the possible mineralogical composition based on chemical analysis. By

eliminating from consideration the mica and iron oxide observed in the glass, it is easy to determine from the measured density of the rock that the density of the glass is not far above 2. Thus the theoretical complete crystallization of glass or fused equivalent in the contact phase of the limestone has involved a diminution in volume of perhaps 19 per cent, or about 15 per cent if pore space be taken into account.

It may be concluded in general that the actual density of the altered rocks is less than that of the fresh limestone, largely because of the development of pore space and glass, but that the densities of the minerals of the altered rocks are on the whole slightly higher than those of the fresh limestone.

Exceptional contact phases, consisting almost entirely of silica or garnet or other constituents, give other density results.

If the principal chemical change in the development of the contact phase has consisted in the elimination of calcite and to a less extent of magnesia, iron, and potassa, leaving alumina and silica substantially unchanged in their ratios, as held to be possible in an earlier paragraph (p. 32), this has involved a very considerable loss of weight (see analyses, p. 27), and, as the densities of the fresh and altered rocks differ so little, the loss in volume also has been large. Kemp,[a] Lindgren,[b] and others have cited lack of structural evidence of diminution in volume at limestone contacts as favoring the view that materials must have been introduced from without to take the place of the calcium carbonate. In the Iron Springs district the field evidence does not positively prove or disprove important volume change, but there is no apparent field evidence to contradict the evidence for diminution of volume here calculated. The limestone, though tilted away from the andesite laccoliths, nowhere shows evidence of crumpling or crowding where the bedding can be observed. In the altered phase the bedding has been destroyed, and it is easy to conceive that this structurally amorphous zone may represent only a part of the volume of the original rock, the calcium carbonate having been driven off and the other constituents concentrated. The change in volume of the limestone would scarcely be expected to stand out conspicuously in the field relations, for it has occurred, if at all, in the band which now does not show original textures or structures, by which change of volume can be measured in crumpling or folding.

In general it appears that there may have been important diminution of volume, accomplished essentially by loss of materials and not by change of density of minerals.

a Kemp, J. F., Ore deposits at the contacts of intrusive rocks and limestone and their significance as regards the general formation of veins; Econ. Geol., vol. 2, 1907, pp. 1–13.

b Lindgren, Waldemar, The copper deposits of the Clifton-Morenci district, Arizona; Prof. Paper U.S. Geol. Survey No. 43, 1905, 375 pp.

Physical conditions of contact metamorphism.—The andesite in its molten state may be supposed to have had a temperature common to acidic silicate solutions under similar conditions anywhere from 500° C. up; probably above 1,000° C. After sufficient heat had been communicated to the limestone to raise the temperature to 550° C., expulsion of carbon dioxide began, and continued during the subsequent increase in temperature. For any given temperature above 550° C. expelled carbon dioxide has a definite pressure which must find relief, if liberation of the carbon dioxide is to continue. The nearly complete elimination of carbon dioxide along the andesite contact indicates that the pressure was not sufficient to restrain its exit; that the pressure was therefore small; and that continuous openings for escape to the surface probably existed.

When the temperature reached 1,100° C. there probably began the incipient fusion of the alumina, silica, lime and magnesia, which remained in the limestone in about the proportions of a calcareous clay. The presence of lime in clay permits fusion at about this temperature.[a] The pore space in the limestones, possibly increased by the expulsion of carbon dioxide, was eliminated, probably in part by pressure, but certainly and completely by fusion. Had the temperature not reached 1,100° it is possible that a porous texture would have resulted, such as that sometimes seen along the limestone contacts with igneous rocks,[b] which would have favored the introduction of new substances in the contact phase to a larger extent than is here observed.

After the limestone reached its maximum temperature, probably somewhat below that of the andesite magma, the temperature slowly fell, allowing fairly coarse crystallization of both andesite and limestone. Local chilling, however, developed glass in parts of the fused limestone mass, and the glass remains, at least in part, to-day. The introduction of the ore-bearing solutions accompanied or followed the crystallization, and still later came the mineral-bearing waters from the late lavas. The minerals of these different periods are listed on page 85.

SANDY PHASE OF LIMESTONE.

The altered contact phases of limestone are often hard to distinguish from a much-fractured quartzite or clayey sandstone which is locally exposed below the limestone and constitutes a part of the same formation. The sandstone lies between the ore deposits and the andesite, or between the ore and the limestone. It is conspicuous also in the limestone patches faulted into the andesite. In

a Ries, Heinrich, and Kümmel, H. B., The clays and clay industry of New Jersey: Final Rept. State Geologist New Jersey, vol. 6, 1904, p. 103.

b Barrell, Joseph, The physical effects of contact metamorphism: Am. Jour. Sci., 4th ser., vol. 13, 1902, pp. 279-296.

the large-scale detail maps of the ore deposits (Pls. III–VI, in pocket) the lower sandy phase and the metamorphosed phases of the blue limestone have been separated from the typical blue limestone but not from each other.

Unless the structural relations are clear, both the sandy and silicated contact phases of the limestone are likely to be confused with the Cretaceous sandstone which occurs in isolated patches in the andesite.

FOSSILS.

The fossils found in the Homestake limestone are few and poorly preserved. Only one genus, *Aviculopecten*, ranging from Silurian to Triassic, was identified by Prof. Eliot Blackwelder, of the University of Wisconsin. There are fragments, however, which appear to be referable to *Edmondia*, a Carboniferous genus.

STRUCTURAL RELATIONS AND THICKNESS.

The Homestake limestone is intruded by the laccoliths. The contacts are usually nearly vertical, sometimes because of later faulting. In a few localities, as at the Desert Mound, in the southwestern part of the Iron Mountain laccolith, and south of The Three Peaks, the limestone rests against and upon the laccolith with a gently dipping plane of contact, though locally even here the contacts are steep because of faulting. In the circular ridge east and southeast of the Iron Mountain laccolith the dip of the Pinto sandstone and the Claron formation is steeply toward the andesite, suggesting an overturned fold in which the Homestake limestone probably participates.

The Homestake limestone is overlain conformably by the Pinto sandstone, with a shale at the base.

The thickness of the Homestake limestone, as shown by exposures, ranges from 500 to 50 feet. The average thickness has been taken to be about 200 feet. The variation is probably due to intrusion of laccoliths at different horizons. If the intrusion has followed the base the variation in thickness may indicate unconformity with the overlying Pinto sandstone.

CRETACEOUS SYSTEM.[a]

PINTO SANDSTONE.

DISTRIBUTION.

The Pinto sandstone for the most part borders the Homestake limestone on the side away from the laccoliths. On the west side of The Three Peaks it extends several miles westward from the band of Homestake limestone and disappears under the desert clays and

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[a] Jurassic in part, perhaps.

gravels. On the southwest end of. The Three Peaks laccolith the Pinto sandstone is in contact with the andesite in several places, but farther east it again appears in its normal place outside of the Homestake limestone, and continues until covered by the later clays. The formation borders the north, east, and south sides of the Homestake limestone and the andesite of Granite Mountain, and a tongue extends northward into the desert. South and west of the Desert Mound there are also considerable exposures. Patches are exposed south and about three-fourths of a mile northwest of Iron Springs.

In the southwest quarter of the district a belt of Pinto sandstone extends around the Iron Mountain laccolith, widening out to the west and southwest. A small area is found southwest of the Homestake mine, within the area of the Iron Mountain laccolith. North of Iron Mountain there are several small areas of sandstone exposed outside of the Claron limestone surrounding the Antelope Range lavas. A belt surrounds the Stoddard Mountain intrusive, which is just on the southern edge of the area mapped.

CHARACTER.

The Pinto formation is composed mainly of brown, yellow, gray, maroon, and spotted sandstone, both coarse and fine grained. Interstratified with these in the lower part of the formation are maroon, purple, and green shales, a few beds of conglomerate, and a few of gray, sandy, brecciated limestone. None of these interstratified beds are continuous throughout the area. In the Granite Mountain and Three Peaks areas the lower part of the Pinto formation has a characteristic succession, only a few members of which are present in the area about Iron Mountain. A generalized section for the first two areas is as follows:

Generalized section of Pinto formation in Granite Mountain and Three Peaks areas.

		Feet.
7.	Yellowish brown and gray sandstone	1,000+
6.	Conglomerate with interbedded sandstone	20–40
5.	Variegated sandstone and shale	40–75
4.	Conglomerate	8
3.	Cherty limestone breccia	10–20
2.	Maroon and spotted sandstone	40–60
1.	Purple and green shale	30–50

The shales (1) at the bottom, in contact with the Homestake limestone, are fairly continuous, being found throughout the northeast quarter of the district, and at one locality east of Iron Mountain, though here only the green shale is present. They are soft, sandy, and much fractured.

The maroon and spotted sandstones (2) are abundantly exposed in the northeast quarter of the area, but appear locally at other points,

as east of the Homestake mine, south of Crystal Springs, and around the southwest corner of the Iron Mountain laccolith. They are comparatively soft and friable and are generally of a deep maroon color; at the base are beds of white sandstone having deep red spots. The grains are mostly quartz and the different colors are due to iron oxide in the cement.

The cherty limestone breccia (3), although thin, is another characteristic bed in the lower part of the Pinto formation. It is present around The Three Peaks laccolith, north of the Granite Mountain laccolith, and east of the Desert Mound, at all of which places it occupies the same part of the series. It is a dark grayish-blue brecciated limestone. The fragments vary in dimensions from a fraction of an inch to 6 inches, and are separated by narrow bands or veinlets of chert, which on weathered surfaces may project as much as a quarter of an inch above the rest of the rock. Under the microscope the fragments appear to be made up of exceedingly fine grains of calcite, with here and there veins of coarser calcite.

The lower conglomerate (4) is associated, almost without exception, with the brecciated limestone, but it is also found in parts of the district where the latter is not present. Wherever identified it has been mapped with the conglomerate symbol. It is exceedingly well cemented, so that on breaking, the fractures occur for the most part through the pebbles instead of around them. This is true especially in the northeast quarter of the area. The pebbles are chiefly quartz, black chert, quartzite, and dark limestone, the latter probably being obtained from the Homestake formation. The matrix is composed of rather fine-grained sand, the whole being well cemented by silica.

Between the lower and upper conglomerates there are a number of sandstone and shale beds (5), none of which are continuous over any considerable area. West of The Three Peaks the lower part is characterized by light-green shale about 20 feet in thickness, overlain by a purple shale about half as thick. Above this are fine-grained flaggy sandstones, white, gray, and mottled in color. West of Granite Mountain and south of The Three Peaks the shales are entirely absent, being replaced by coarse- and fine-grained sandstone.

The upper conglomerate (6) appears throughout most of the northeast quarter of the area. It consists of heavy conglomerate layers alternating with thin layers of sandstone, the pebbles composing the former being of the same kind as those of the lower conglomerate but as a rule larger, especially where the formation is thick, and less firmly cemented. Around the Iron Mountain laccolith only one conglomerate is present, presumably the lower, since at several places a maroon sandstone is found between it and

the Homestake formation. In the northeast quarter of the district this conglomerate also has been mapped.

Above the conglomerate beds throughout the district is a great thickness of gray, yellowish-brown, or red sandstones (7), forming by far the largest part of the Pinto formation. These are normally coarse and friable, but where parts of the Pinto formation come in contact with the laccolithic andesite they are fine grained and quartzitic. The sandstone becomes coarser in its upper part, and near the top contains a layer of coarse conglomerate. During the erosion interval at the end of the Cretaceous this conglomerate was so largely removed that at present it is found only locally near the overlying Eocene deposits.

Limestone lenses appear in the Pinto sandstone along the southwestern edge of The Three Peaks, immediately southwest of Iron Springs, and in the middle of the valley halfway between these areas. Other lenses are exposed in Oak Springs Flat, east of Iron Mountain, where they are partly obscured by late unconsolidated deposits. These lenses are in the lower part of the Pinto formation, but their exact position in the preceding succession is not known.

The limestones are much fractured and brecciated. Their color varies, in different parts of the district, from dark gray to light gray and even pink. The latter is very much like the Claron limestone and is distinguished from it only by its brecciated character.

CONTACT METAMORPHISM BY LACCOLITHS.

At or near the contact of the Pinto sandstone with the laccolithic andesite the sandstone is quartzitic, and the yellow, brown, and red colors are replaced by gray and white. In places the rocks are mottled or have concentric dark-colored rings (Pl. XXI, A, p. 74), which, under the microscope, appear to be irregular aggregates of small elongated crystals of colorless amphibole. The metamorphism is commonly noticeable for a few hundred yards from the contact, and west of Iron Mountain it is seen as far as a quarter of a mile.

FOSSILS.

No fossils were found in the Pinto sandstone. This absence of fossils and the association of red sandstones and shales suggest terrestrial deposition.

STRUCTURAL RELATIONS AND THICKNESS.

The relations of the Pinto sandstone to the underlying Homestake limestone have already been discussed. The relations with the overlying Claron formation are unconformable, as evidenced by a basal conglomerate and by the partial erosion of certain well-recognizable beds near the top of the formation. There seems to be

little unconformity of dip, however, indicating that the period of erosion between Cretaceous and Tertiary was not characterized by folding.

In general the Pinto sandstone dips steeply away from the laccoliths, but south of The Three Peaks, at the Desert Mound, and west of Iron Mountain the dip is gentle. East of Iron Mountain the dip is steeply toward the laccolith; to the southeast it gradually becomes vertical; and south of Iron Mountain it is steeply away from the laccolith. East of Upper Point, south of Joel Springs Canyon, and elsewhere the beds are nearly horizontal.

It is hard to determine the thickness of the Pinto formation because of the abundance of faults. The greatest thickness exposed in cliffs is about 500 feet, but thicknesses across the formation southeast of Iron Mountain, calculated from the dip and width of exposure, are as high as 3,500 feet. The average thickness is considerably over 1,000 feet.

TERTIARY SYSTEM (EOCENE).

CLARON LIMESTONE.

DISTRIBUTION.

The Claron formation surrounds the laccoliths outside of the Pinto sandstone. In the northeast quarter it occupies an area just inside of the north boundary of the area shown on the map. It is much faulted, giving an irregular contact between it and the Pinto sandstone to the south.

East of Granite Mountains the Claron limestone occupies an area which, on account of faulting, is broad at the north and narrow at the south and west. Narrow strips of the formation follow the northwestern base of the Swett Hills.

Southwest of the Antelope Range the Claron limestone comes out from underneath the lavas and extends eastward to where it is covered by the Pleistocene lake deposits and southward to where it has been eroded away from the underlying Pinto sandstone. In Chloride Canyon, southwest of the Antelope Range, and northwest of Iron Mountain it appears again, owing to the erosion of the overlying lavas.

The largest area of Claron limestone in the district borders the eastern and southern sides of Iron Mountain, then goes outside of the area, but reappears west of Iron Mountain, on the border of the area shown on the map. Both by its distribution and by its structure it brings out well the laccolithic shape of the andesite mass.

On the northeast side of the Harmony Mountains little areas of Claron limestone are brought up by faulting. It appears also west of the Stoddard Mountain intrusive.

CHARACTER.

The Claron formation is mainly limestone with numerous thin layers of conglomerate and a few heavy beds of sandstone. It is separated from the Cretaceous sandstones by a basal conglomerate 2 to 25 feet thick, made up of coarse quartzite pebbles where it is thick and of finer pebbles where it is thin. Below it is generally a soft, pink, calcareous sandstone or soft limestone, which probably represents residual material from the weathering of the Pinto formation formed before the deposition of the Eocene. It is only a few feet thick and under it are the red and yellow sandstones of the Cretaceous. Locally the underlying Cretaceous bed is a coarse conglomerate difficult to distinguish from the basal conglomerate of the Claron formation. In most places it was eroded away before the deposition of the Claron. Above the basal conglomerate is another conglomerate, thin and sandy, with small pebbles, and discontinuous. It is like numerous other conglomerates interbedded with the limestone higher up in the formation. These as a rule are thin and any single bed is not continuous over a large area. The pebbles are small and are separated by a matrix of coarse sandstone. They are mainly quartzite, limestone, quartz, and chert, in varying proportions in the different beds. The conglomerate beds may grade laterally into coarse sandstone beds.

The principal part of the formation is a sandy limestone varying from white and gray to pink, red, and purple. On weathering, the sand grains, being less easily dissolved, protrude above the surface and give it a rough pitted appearance. Some of the layers have spherical and irregular cherty concretions which vary from less than half an inch to an inch or more in diameter. The limestones are more resistant to erosion than the sandstones and conglomerates of the Eocene and Cretaceous, and hence form cliffs and ridges above them. On weathering they acquire bright-red colors, making the exposures conspicuous for many miles.

Heavy yellowish-brown sandstone beds containing a number of discontinuous layers of conglomerate are interbedded with the limestones. Owing to faulting, it is hard to tell the thickness of these sandstones, but it may be several hundred feet. In some places they are distinguished with difficulty from the Cretaceous sandstone. Criteria for their identification are their occurrence in the midst of Tertiary rocks, and the absence of a basal conglomerate between them and the overlying limestone and conglomerate beds. The first of these might be caused by faulting, but the invariable absence of the basal conglomerate in such cases was taken as evidence that they were Tertiary.

FOSSILS.

No fossils were found in the Eocene limestone, but a number were found in the limestone and chert pebbles of the conglomerate beds. The following forms, which are mainly Carboniferous, were identified by Prof. Eliot Blackwelder:

Fossils from the Claron limestone.

Productus sp.	Spirifer sp.
Fenestella sp.	Zaphrentis sp.
Lithostrotion sp.	Crinoid stems and bryozoans.
Rhynchonella sp.	

They show only that the Claron sediments are post-Carboniferous.

STRUCTURAL RELATIONS AND THICKNESS.

The relations of the Claron limestone to the underlying Pinto sandstone have been discussed. On the upturned and eroded edges of the Claron limestone lie the Tertiary lavas in nearly horizontal beds.

The dips of the Claron limestone are slightly less than those of the Pinto sandstone because of their greater distance from the laccoliths. In a few places the beds are nearly horizontal, as south of Joel Springs Canyon and at Mount Claron.

A large amount of faulting has taken place in Eocene areas, some of which has undoubtedly remained undetected because of the similarity of different parts of the formation. Most of it dated after the laccolithic intrusion and before the later lavas were poured over the area, as shown by the fact that certain of the limestone areas are much faulted while the adjacent lava beds are undisturbed. A few faults traverse both formations indiscriminately, thus showing a later period of faulting.

The thickness of the Claron formation varies in different parts of the quadrangle, owing to erosion both before and after the laccolithic intrusion. The average thickness is about 1,000 feet, but all estimates are largely vitiated by faulting.

CONTACT METAMORPHISM BY EFFUSIVES.

Adjacent to the lavas the limestone has a layer of white, gray, or red chert, chalcedony, and moss agate or jasper, which is sometimes 10 to 15 feet in thickness. The red moss agates and jaspers are colored with iron. With these cryptocrystalline varieties of quartz is often associated a white powdery calcium carbonate, apparently deposited by hot springs. This is especially abundant north of the Eightmile Hills. The same powdery carbonate is frequently associated with the ore deposits.

At Chloride Canyon and elsewhere the limestone contains mineral veins near the contact with the lavas. The minerals are mainly calcite, barite, and quartz, with subordinate amounts of galena, pyrite, chalcopyrite, siderite, limonite, magnetite, and copper carbonates. Gold and silver are reported, the latter probably being present in the galena. Similar mineral veins are found in the Homestake limestone, both associated with and away from iron-ore deposits.

QUATERNARY SYSTEM.

PLEISTOCENE CONGLOMERATE.

The Pleistocene conglomerate is exposed only east of Antelope Springs, in the northwest corner of the area, where it occupies a little embayment in the lava area. To the north it is covered by later lake and outwash deposits. In the Pleistocene conglomerate area a few exposures of Tertiary limestone and conglomerate were noted, but it was not possible to tell whether these were outcrops of actually underlying formations or merely huge bowlders partly buried. There being no definite proof of the former, these exposures were not mapped. The formation is probably present west of The Three Peaks, overlying the Cretaceous and overlain by surface deposits, but only one outcrop was found and this was too small for the scale of the map.

The conglomerate is composed of both rounded and irregularly shaped fragments of limestone, chert, sandstone, and lavas, derived from immediately adjacent rock formations and cemented by a reddish sandy calcareous material, forming in places a fairly well-consolidated rock. It is rather thinly bedded, some of the beds being made up of coarse conglomerate, and others of finer sandy materials. From the thinly bedded character and rapidly varying materials of the different beds it seems clear that the formation is of fluviatile or terrestrial origin, deposited by streams as they emerged from the mountainous areas.

The Pleistocene conglomerate is unconformable upon the Tertiary lava series, in horizontal beds which retain no evidence of faulting. Its thickness is not known, but it is likely not more than 200 feet at the most.

PLEISTOCENE AND RECENT GRAVEL, SAND, AND CLAY.

Gravel, sand, and clay, derived from the neighboring rock hills, cover the lower slopes of the hills and the desert areas as lake, stream, and outwash deposits. To the east are the deposits of Rush Lake Valley, which run northeastward along the Colob front. To the west and north are the deposits of the Escalante Desert, which extend 35 or 40 miles westward and far to the north.

In the Escalante Desert clay is found mainly along the washes and in the low areas bordering them, while the gravels and sands are found in the areas between the washes. These coarser materials are fairly well rounded and appear to have been sorted.

The area around Shirts Lake is composed of fine clay with a white coating of alkaline carbonates. Around the entrance to Leach Canyon and in Rush Lake Valley east of Iron Springs are rolling hills of coarse subangular and rounded gravels, similar to those in the Escalante Desert.

Outwash fans of fine and coarse angular material border all the hilly areas and extend out into the desert for half a mile or more. Some of these are perfectly fan shaped, but in general the separate fans encroach upon one another laterally and form continuous outwash aprons along the borders of the hills. They have a relatively steep slope near the hills and gradually become less steep until they merge imperceptibly into the flat deserts.

These are the latest deposits in the area, and they are still accumulating. Their thickness is not known.

CHAPTER IV.

IGNEOUS ROCKS.

The igneous rocks of the district are both intrusive and effusive. The intrusives are biotite andesite laccoliths intruded into the Paleozoic and to a less extent into the Mesozoic rocks after the deposition of the Tertiary sediments. The effusives are later and form a bedded series varying in thickness from 1,000 to 2,000 feet and consisting of rhyolitic, trachytic, and andesitic flows, tuffs, and breccias.

The lavas rest on the eroded and upturned edges of the Eocene and Cretaceous sediments, indicating a considerable period of erosion between the intrusion of the biotite andesite and the outpouring of the effusives. The latter have been correlated with the Miocene lavas of the Wasatch Mountains, hence the andesite intrusion is post-Eocene and probably early Miocene.

The Quaternary basalts, present on all sides of the area, are not present within the district.

LACCOLITHS (EARLY MIOCENE).

DISTRIBUTION AND STRUCTURE.

The laccoliths are exposed in three main areas forming the cores of the principal mountains of the district—The Three Peaks and Granite Mountain in the northeastern and Iron Mountain in the southwest part. A fourth, Stoddard Mountain, lies mainly beyond the southwest side of the area mapped. The laccolith areas are circular, with local irregularities due to faulting and other causes. Northwest of the The Three Peaks a small area of biotite andesite is brought up in contact with the Claron limestone by a great fault. Northwest of Iron Mountain a wide dike of andesite breaks through the Pinto sandstone a short distance from the main laccolithic mass, while to the southwest, surrounded by sediments, are several small andesite areas, parts of the large andesitic mass exposed through erosion of the low-dipping overlying limestone. In The Three Peaks and Iron Mountain laccolithic areas there are small patches of sediments faulted down into the andesite or left as erosion remnants.

In general the sediments dip away from the andesite, although locally, as east of Iron Mountain, the dip is steeply toward it, suggesting overturned strata. The strike of the beds is always parallel, or nearly so, to the andesite contact, except where faulting has

caused irregularities of structure. Individual strata of sediments may be followed almost entirely around the andesite areas. The contact with the sediments is commonly steep and the dip of the sediments less steep. Less commonly both the dip of the contact and of beds is low. The dip of beds and contact varies with depth of erosion. Nowhere has erosion exposed the base of the laccoliths, though the tops are well stripped. The maximum thickness exposed is 1,600 feet.

The circular outline of the intrusions, the manner in which the sediments encircle them and rest against and upon them, and the texture of the andesite favor the view that they are laccoliths (Pl. II, pocket). With their relations to the sedimentary rocks, the only alternative explanation would be that of a batholitic intrusion, and against this stands their texture and the lack, in the surrounding sediments, of the schistosity that often characterizes a plutonic contact. It is with some confidence, therefore, that the andesite masses are concluded to be laccoliths, notwithstanding the lack of direct observation of shape of the lower parts.

According to Gilbert's study of the laccoliths of the Henry Mountains,[a] the pressure of injection remaining constant, the limital area of a laccolith is a direct function of its depth beneath the surface. The limital area is greater when the depth is greater, and less when the depth is less. A laccolith with the diameter of the Iron Mountain laccolith would require a minimum of 7,000 feet of covering. A possible covering of about 4,500 feet can be measured on the eroded edges of the surrounding sediments. If Gilbert's conclusion be a sound one, it may be inferred that in the Iron Springs district certain sediments have been completely removed by erosion. His calculation, however, is based on the assumption that the sediments have been elastic and free to slide one over the other during the intrusion. If, on the other hand, the overlying sediments have any considerable strength, developing resistance beyond that afforded by the weight, the size of the laccolith would be proportionally increased. Such resistance may well be possessed by the Homestake limestone, which in all but a few places immediately overlies the laccolith, and the large size of the Iron Springs laccoliths may be due to this cause rather than to any greater depth of covering than can be measured on the sediments now present in the area.

A similar conclusion as to the factors determining the horizon of the laccoliths is reached from a consideration of densities. The density of the andesite is 2.65. The mean density of the rocks known to overlie it is about 2.54. Gilbert argues for the Henry Mountains that the laccoliths came to rest in such a position that their density

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a Gilbert, G. K., Report on the geology of the Henry Mountains: U. S. Geog. and Geol. Surv. Rocky Mtn. Region, 2d ed., 1880, p. 84.

is slightly above the mean density of any combination of the over-
lying sediments. The density of the Iron Springs laccoliths, now
2.65, was considerably lower before solidification, presumably lower
than 2.54, the mean density of the overlying sediments, suggesting
that the Iron Springs laccoliths came to rest not in places deter-
mined by the law of hydrostatic equilibrium but in places determined
by the competency of the restraining limestone and sandstone strata;
in other words, the Iron Springs laccoliths, if their density at the
time of the intrusion was that common to acidic intrusives of this type,
would have been intruded more nearly at the surface had it not
been for the strength of the restraining limestone.

PETROGRAPHY.

The intrusive andesite is the rock with which the iron-ore deposits
are associated. Deposits are found on the borders of all the andesite
areas except Stoddard Mountain, where its absence is probably due
to the absence of limestone.

The rock is a light-gray biotite andesite with porphyritic texture.
The phenocrysts, consisting of feldspar, biotite, hornblende, and
diopside, are numerous, occupying more than half of the rock mass,
and varying in size up to an eighth of an inch in diameter. The
most abundant phenocryst is plagioclase of the variety labradorite,
but orthoclase is occasionally present. A large number of feldspars
show zonal growth. They are comparatively fresh, showing altera-
tion only along cracks, along lines of zonal growth, and on the sur-
face. The alteration products are calcite, kaolin, quartz, and seri-
cite, typical katamorphic products. The next most abundant
phenocryst is biotite, in shiny black hexagonal plates, often altered
to phlogopite with a golden luster and frequently having reaction
rims of magnetite. In the Stoddard Mountain area and parts of the
other areas, the biotite is almost entirely decomposed to ferrite. In
a few cases it has altered to green chlorite. The biotite has abun-
dant inclusions, mainly apatite but sometimes quartz, magnetite
and zircon. The hornblende is generally in dark-green prismatic
crystals, with inclusions of magnetite, biotite, and quartz. Like
the biotite, the hornblende in the andesite of the Stoddard Mountain
area is almost entirely decomposed to ferrite. The diopside is of a
light-green color, and is noticeably associated with magnetite, which
is present as inclusions and around the borders. It is generally
more or less altered to uralite along cracks and around the border.
Fragments of magnetite are abundant throughout the rock. Ferrite
is present as an alteration product of the ferrous silicates.

The groundmass is cloudy from alteration, but seems to be com-
posed mainly of fine crystalline quartz and feldspar, both orthoclase
and plagioclase. Biotite, hornblende, pyroxine, and magnetite are
also represented, but less abundantly.

A
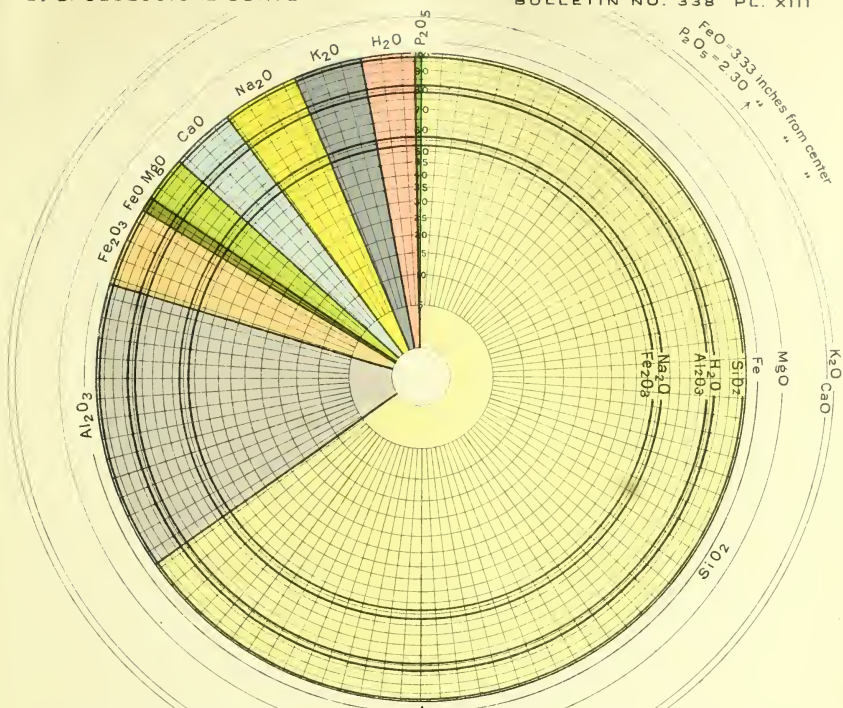
GRAPHIC COMPARISON OF COMPOSITION OF ALTERED ANDESITE, ANALYSIS "C,"
WITH FRESH ANDESITE

B
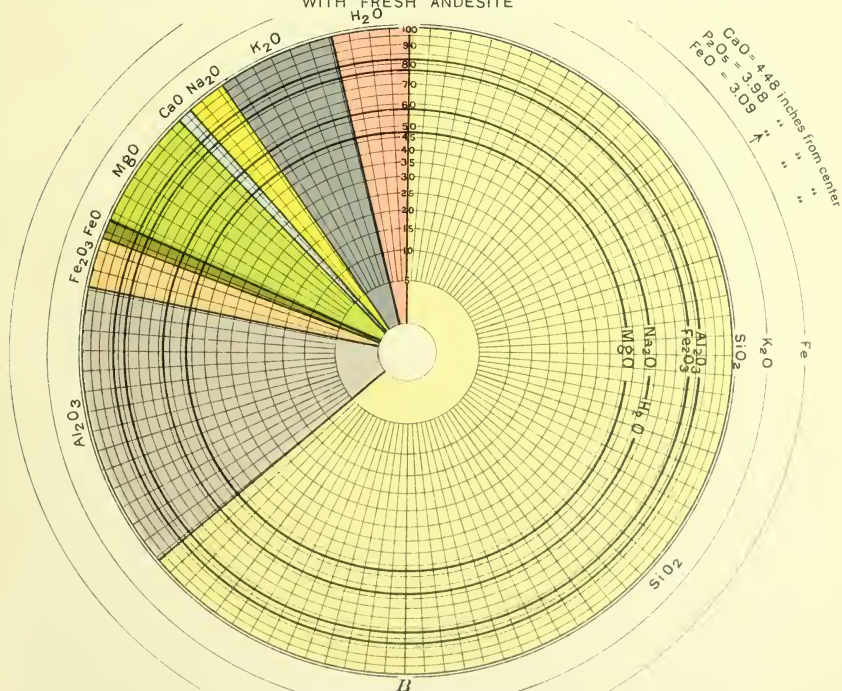
GRAPHIC COMPARISON OF COMPOSITION OF ALTERED ANDESITE, ANALYSIS "D,"
WITH FRESH ANDESITE

The biotite andesite has the same texture and mineral composition throughout the different areas. The absence of marginal facies (as a basic edge), dikes, and pegmatic veins is especially noticeable.

METAMORPHISM OF ANDESITE BY THE ORE-BEARING SOLUTIONS.

Near its contact with the ores for a few feet the andesite takes on a greenish-yellow color and dense texture, very similar to that of the silicated limestone at the andesite contact. The two are with great difficulty discriminated. The grain of the contact phase is much finer than that of the main mass of the andesite. The groundmass consists of finely crystalline feldspar and quartz, principally the former, cloudy with dark clayey-looking material, much of it not recognizable, but some of it in the larger masses clearly muscovite and rarely chlorite. The contact between the altered phase and the fresh andesite is sharp.

A comparison of the analyses of the fresh and contact phases by the circular-diagram method (Pls. XIII and XIV) brings out clearly the fact that at the contact the conspicuous change has been the introduction of soda. All other constituents show a possible loss, though ferric iron has developed at the expense of ferrous iron. In the present state of development of the district it is not possible to secure specimens from horizons surely below the influence of weathering. It may be that the oxidation of the ferrous iron here indicated is really a superposed weathering effect.

When the normal weathered andesite from the surface is compared with the fresh andesite, as in the following table (see also Pl. XII, *B*, p. 30), the change is found to be of quite a different character from that along the ore contacts. All constituents, including soda, show a loss relative to the alumina, as in Pl. XII, *B*.

Analyses of fresh and altered andesites.

[Analyst, R. D. Hall, University of Wisconsin.]

	A.	B.	C.	D.	E.
SiO_2	65 29	63. 63	65 80	63.82	63. 76
Al_2O_3	11. 57	15. 64	14. 48	14. 28	16. 05
Fe_2O_3	2. 10	3. 59	3. 96	2. 72	1. 91
FeO	2. 67	. 93	. 70	. 81	. 58
MgO	2. 87	2. 32	2. 35	5. 98	2. 46
CaO	4. 85	4. 46	3. 19	. 70	4 25
Na_2O	2. 10	1. 70	3. 78	3. 62	6. 26
K_2O	5 18	5. 22	3. 32	4. 24	2 84
H_2O-	. 50	. 40	12	2. 30	1. 22
H_2O+	1. 82	1. 70	2. 71	1. 68	. 93
P_2O_5	. 22	. 15	. 12	. 04	. 28
BaO	. 17	. 05	. 06	. 04	None.
	99. 34	99. 79	100. 59	100. 23	100. 54

A. Specimen 46612.   Fresh andesite east of Granite Mountains.
B. Specimen 46377.   Weathered andesite from Desert Mound.
C. Specimen 46433.   Altered andesite near iron-ore contact from Blowout, south of Iron Mountain.
D. Same nearer iron ore contact.
E. Specimen 46481.   Altered andesite near iron-ore contact from Emma claim on east slope of Iron Mountain.

EFFUSIVES (LATE MIOCENE).

DISTRIBUTION AND STRUCTURE.

The effusives occupy two main areas in the district—the Antelope Range area and the Swett Hills, Eightmile Hills, and Harmony Mountains area. There are small exposures at Upper Point, in the northeastern quarter, and northwest of Iron Mountain.

There is a succession of 9 flows in the following order:

Succession of lava flows in Iron Springs district.

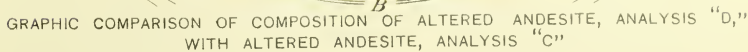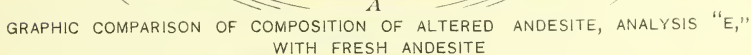|	Feet.
9. Biotite-hornblende-pyroxene andesite	200
8. Late tuffaceous rhyolite (Antelope Range)	400
7. Biotite dacite	300
6. Pyroxene andesite agglomerate and breccia	100
5. Latest trachyte	150–300
4. Hornblende andesite breccia and agglomerate	150
3. Later trachyte	50
2. Early tuffaceous rhyolite	300–400
1. Early trachyte	50–600

Of these Nos. 1, 2, 5, and 7, extend throughout the area and for a number of miles to the south and west, while the rest are present only in parts of the district. There is little evidence of erosion between the successive flows, unless the absence of certain beds in different places be taken as such. The oldest formation forms the border of the lava series and inside of this successively younger flows outcrop, the latest in the center. Local faulting and sheets of outwash deposits have somewhat obscured these relations in places.

The Antelope Range lavas occupy a broad syncline pitching to the northeast, while those of the Swett Hills and Harmony Mountains have a general eastward dip and are not folded.

PETROGRAPHY.

Early trachyte.—The rocks of the early trachyte bed differ considerably in texture in different parts of the district as well as in different parts of the series. The color and mineralogical character, however, remain the same throughout the district. In general the rocks are dark and dense with few phenocrysts, principally feldspar, subordinately biotite.

In the Antelope Range, where it is typically exposed, the main part of the formation is a dense dark-red or purple porphyritic trachyte with very few phenocrysts. The phenocrysts are mainly orthoclase, and to a less extent plagioclase, of the variety andesine-labradorite. Both feldspars show Carlsbad twinning. They are altered along cracks and on the borders to quartz and calcite. The groundmass is dense, and in some layers contains amygdules, which are partly or

GRAPHIC COMPARISON OF COMPOSITION OF ALTERED ANDESITE, ANALYSIS "E,"
WITH FRESH ANDESITE

GRAPHIC COMPARISON OF COMPOSITION OF ALTERED ANDESITE, ANALYSIS "D,"
WITH ALTERED ANDESITE, ANALYSIS "C"

entirely filled with quartz and chalcedony. Near its base the trachyte in places becomes ferruginous, yielding from 6 to 7 per cent of iron.

The upper 30 feet of the bed has a somewhat varying character in the Antelope Range area, being composed of a main layer of lavender-gray trachyte, with thin layers of tuffaceous, scoriaceous, and dense trachytes, and has been mapped separately as far as it could be distinctly traced.

In the Swett Hills the early trachyte bed is dark gray and the phenocrysts are few. In the Eightmile Hills it is red, with numerous phenocrysts of sanidine and plagioclase and fewer of biotite. East of the Eightmile Hills and in the Harmony Mountains parts of the bed are porous and even scoriaceous, and have a predominance of lime-soda feldspar over orthoclase. In Cottonwood Canyon and westward it is complicated by additional beds of rhyolite, trachyte, and andesite similar to some of the overlying lavas. South of Iron Mountain the bed is amygdaloidal. The amygdules are spherical or oblong in shape, varying from 5 to 50 millimeters in diameter, and are filled with quartz and calcite.

Early tuffaceous rhyolite.—In the northeast and in the southern part of the Antelope Range area the early tuffaceous rhyolite bed is of uniform character throughout its vertical extent. It is a light-gray, pink, or white porphyritic rock with numerous phenocrysts, and small irregular fragments of other volcanic rocks. The phenocrysts are mainly quartz, orthoclase, and plagioclase, with less abundant biotite and hornblende. Zonal structure, secondary enlargement, and inclusions of long narrow crystals of apatite are common. The biotite is largely altered to phlogopite and is frequently associated with magnetite. Pyroxene appears in the included rock fragments, but not in the rhyolite itself. The groundmass is amorphous, except for small crystals of quartz and feldspar and cavities which are partly or wholly filled with chalcedony or calcite.

The early rhyolite bed in and near the Antelope Range in the western part of the Antelope Range area differs somewhat from the above. The succession, beginning at the bottom, is (1) a few feet of gray or black rhyolitic pitchstone, with numerous phenocrysts of quartz, feldspar, and mica; (2) hard red rhyolite which grades up into (3) a light-red rhyolite with numerous fragments of other volcanic rocks. (2) and (3) grade laterally into the tuffaceous phase of the eastern part of the area, but (1) does not change its character and is found in the same position, viz, at the bottom of the early rhyolite series, throughout this area as well as in other parts of the quadrangle. The minerals in these 3 phases are very much the same as in the tuffaceous phase, except that little or no hornblende is present. The feldspars are mainly orthoclase, but plagioclase is fairly abundant. They are altered to calcite, kaolin, and quartz, the plagioclase more

so than orthoclase. Quartz shows strong resorption, but is otherwise fresh and limpid. Under the high power, it shows inclusions. The biotite is black and shiny and has inclusions of apatite. Magnetite and ferrite are present in small quantities, the latter as an alteration product of the ferrous silicates. Zircon is rare. The groundmass is partly crystalline and partly eutaxitic and amorphous. The crystalline part appears to be mostly quartz and feldspar. There are numerous chalcedony-filled cavities throughout the rock.

The band of early rhyolite along the northwestern front of the Swett Hills is bright pink with phenocrysts of quartz and sanidine, the latter with Carlsbad twinning. Both quartz and feldspar are fresh and glassy. The former frequently shows resorption. The groundmass is pink and dense, but with numerous little cavities. It appears to be amorphous with lenses of lighter colored crypto-crystalline material.

The areas of lower rhyolite in the Eightmile Hills and the Harmony Mountains, like those first described, are more or less tuffaceous in character, but as the groundmass becomes denser they grade into a fragmental rhyolite. The little neck of the early rhyolite bed west of Stoddard Canyon has a number of areas of trachyte and dacite very much like those in the purple trachyte east of Birch Canyon. These are very irregular in extent and distribution and could not be structurally so separated as to correlate them with the overlying trachyte and dacite.

Later trachyte.—Wherever the later trachyte is present it is composed of 2 distinct layers—at the base a black trachytic pitchstone averaging 5 to 10 feet in thickness and above this a dense red trachyte.

The pitchstone contains abundant phenocrysts of feldspar and biotite, and fewer of diopside, hornblende, magnetite, and apatite. The feldspars are largely sanidine, showing Carlsbad twinning. A little plagioclase is present. The feldspars are all fresh and unaltered, and have numerous inclusions of apatite and zircon. The biotite is dark brown and strongly pleochroic. It has few inclusions which are mainly zircon. Magnetite fragments are abundant, some of them showing alteration to hematite. Hornblende is rare.

The groundmass is black and glassy and under the high power appears to be made up of innumerable crystallites with simple and branching hairlike forms grouped along lines of flow. In it are red spherulites, some of which in addition to the spherulitic structure show flow structure like the rest of the groundmass.

The trachyte above the pitchstone is a reddish-brown porphyritic rock with phenocrysts of feldspar and biotite, about equally abundant, and together making up perhaps one-tenth of the mass of the rock. Both orthoclase and plagioclase are present, the latter being probably

a little more abundant. They are very much altered to a white clayey material, probably kaolin. The biotite is fresh, dark brown, and strongly pleochroic. It has a few inclusions of apatite. Magnetite particles are numerous. The groundmass is cloudy from specks of ferrite and shows flow structure, especially around the phenocrysts. It appears to be partly amorphous with tiny specks of feldspar arranged along flow lines. The phenocrysts are also arranged parallel to the lines of flow.

Hornblende andesite breccia and agglomerate.—In the western and northern parts of the Antelope Range area the hornblende andesite is a greenish-gray breccia, but toward the south it grades into a coarse agglomerate, with dark-gray and black fragments. In the breccia the fragments are of dark andesite and rather small, the largest being about 10 inches in diameter, and by far the larger part being smaller. The material between the fragments is of the same character as the fragments but somewhat softer. In the agglomerate the fragments are larger, ranging up to perhaps 2 feet in diameter. Most of them are composed of the same material as the fragments of the breccia, but other fragments are red and trachytic. The intervening material in the agglomerate is light gray and tuffaceous and weathers readily, leaving the fragments strewn around over the surface like bowlders. These soon become black and shiny from desert varnish.

The hornblende andesite composing the fragments is a dark-gray porphyritic rock stained green in many places. The main phenocrysts are narrow crystals of hornblende, sometimes one-fourth inch long. A few phenocrysts of feldspar are present. The groundmass is dark gray and finely crystalline and makes up about nineteen-twentieths of the rock mass. The hornblende has a dark-brown color and shows pleochroism. Fragments of magnetite are found bordering it and included in it, but generally separated from it by an alteration rim of ferrite. The hornblende is altered to ferrite on the surface and sometimes well into the interior.

The ground mass is composed largely of small crystals of orthoclase and plagioclase of the variety labradorite, the latter being a little more abundant. Besides the feldspar, pyroxene, hornblende, and magnetite occur in the groundmass. The small crystals are separated by areas of cryptocrystalline material.

Latest trachyte.—The latest trachyte bed is easily recognized throughout its extent by a characteristic banded appearance. It is composed of several different layers; the full section, which is present only in the eastern part of the Antelope Range area, is as follows, beginning at the base: (1) a few feet of black trachytic pitchstone with phenocrysts mainly sanidine, but with plagioclase, biotite, and

diopside present; (2) red trachyte with grayish-white bands; (3) gray and red trachytes, slightly banded in places; (4) gray tuffaceous trachyte; (5) hard, dense red trachyte. These phases differ only in texture, the phenocrysts (mainly sanidine, subordinately plagioclase, biotite, and magnetite) being the same throughout the series with the exception that layer 5 contains a few pyroxenes, and biotite and magnetite are slightly more abundant than in the other layers. There is also a slight variation in the amount of plagioclase in different parts of the latest trachyte bed.

Outside of the eastern Antelope Range area only layers 1 and 2 and perhaps 3 are present. In the eastern part of the Antelope Range area layer 2 is comparatively thin, but throughout the rest of the quadrangle it forms almost the entire thickness of the bed, although the banding is not always as conspicuous as it is here. The black pitchstone is nearly always present at its base. At the top of the bed in other parts of the quadrangle there is often a layer of less distinctly banded material which may represent layer 3. The absence of the upper layers is probably due to nondeposition, since erosion could hardly have taken place so uniformly over the region as to leave practically the same thickness of trachyte throughout.

The latest trachyte of the Antelope Range (layer 2) is a reddish porphyritic rock, with parallel bands of white and gray material averaging generally less than one-eighth inch in thickness. The phenocrysts, averaging about one-sixteenth of an inch in diameter, form about one-tenth of the rock and are largely sanidine. At the surface these have been entirely leached out, leaving only the cavities. Biotite is also present, being generally altered to phlogopite and often entirely decomposed to ferrite. Phenocrysts appear to be present in both the gray and red bands. Nearly all the sanidine shows Carlsbad twinning. In general, they appear to be quite fresh, showing alteration only on the surface and along fractures. The alteration products appear to be calcite, kaolin, and quartz. The sanidine frequently has inclusions of zircon and apatite. A little plagioclase, variety andesine, is present. Magnetite occurs as fragments.

The red part of the groundmass shows flow structure and is more cloudy than the gray part, owing to numerous little specks of ferrite. It is amorphous for the most part, with here and there specks of feldspar. The gray part appears to be impregnated with quartz. It contains elongated quartz-filled cavities which grade into the more cloudy quartz-impregnated groundmass. In the center of some of the larger cavities there are brownish aggregates of fine cryptocrystalline material. These silicious fillings are probably later than the rest of the rock, having been deposited in the porous parts. This

view is strengthened by the fact that the banded appearance of this formation in other parts of the district is caused by a difference in the character of the ground mass, the lighter bands being porous and the darker ones more dense.

The rocks of the latest trachyte bed over other parts of the district are very similar to the one described above with regard to mineral composition and texture, except for the lesser abundance of quartz in the lighter colored bands.

Pyroxene andesite agglomerate and breccia.— In the western part of the Antelope Range area the pyroxene andesite bed is a greenish-gray copper-stained breccia, with little or no difference between fragments and groundmass. Toward the east it grades into a coarse agglomerate with huge dark bowlder-like fragments, cemented by gray tuffaceous material. This agglomerate is very much like the hornblende andesite agglomerate, but as a general rule it has larger fragments.

The rock composing the fragments in the breccia and agglomerate is a pyroxene andesite. It is dark gray in color and has porphyritic texture, the phenocrysts making up perhaps one-tenth of the rock and averaging one-eighth inch in diameter. The phenocrysts are pyroxene and plagioclase, variety labradorite, the former being the more abundant. The groundmass is dense and appears to be composed of minute crystals. The pyroxene is light green in color, shows a slight brownish pleochroism, and has included magnetite fragments. Often it occurs in aggregates of 2 or 3 and sometimes shows twinning parallel to the orthopinacoid (100). Plagioclase is not very abundant, and has suffered considerable alteration to calcite and kaolin. It shows zonal structure and, like the pyroxene, occurs in aggregates.

The groundmass is composed of numerous crystals of plagioclase and fewer of orthoclase, pyroxene, and magnetite, separated by amorphous areas.

Biotite dacite.—The biotite dacite has the same texture and mineral composition throughout both its vertical and horizontal extent. The color, however, varies slightly. In the Antelope Range area the main part has a reddish-brown color, while at the base there are 50 feet or less of a pinkish-gray color. Outside of the Antelope Range area the latter makes up the entire formation.

The biotite dacite is a porphyritic rock with phenocrysts ranging up to one-eighth inch in diameter and making up fully half of the rock mass. They are mainly feldspar and biotite, subordinately diopside, quartz, and brown hornblende. The feldspars are mainly plagioclase, ranging from basic andesine through labradorite to acidic bytownite. Orthoclase is also present, but not as abundant. A large number of the feldspars show well-developed zonal structure,

the successive zones of growth being very thin, owing to rapidly
alternating conditions in the formation of the crystal. There is con-
siderable alteration along fracture lines, the most important decom-
position product being calcite. The feldspars have inclusions of
apatite and biotite. The biotite is dark brown and greenish brown,
highly pleochroic, and has inclusions of feldspar. The diopside is
light green in color and has numerous inclusions of magnetite. It
is often very much decomposed, the products being calcite and fer-
rite. Fragments of quartz, which frequently show resorption, are
present. The hornblende is of the brown basaltic variety. Frag-
ments of magnetite are abundant.

The groundmass is amorphous and frequently shows flow struc-
ture. Through it are scattered tiny specks of the same minerals as
compose the phenocrysts.

Late tuffaceous rhyolite.—The late tuffaceous rhyolite has the same
character throughout, except for an agglomerate at the base. The
latter consists of big bowlders and smaller fragments of dark igneous
material, both acidic and basic. About halfway up in the tuff forma-
tion there is, in a few places, a thin layer of coarse sandy material,
which appears to be water deposited. Frequently the upper part of
the formation contains numerous concretion-like spheres, ranging
from 1 inch to 5 inches in diameter, which are very much harder and
darker than the rest of the rock. These have the same minerals as
the rest of the formation, but the groundmass is denser and the
cavities have all been filled with chalcedony.

The late tuffaceous rhyolite has a porphyritic texture with pheno-
crysts of feldspar, quartz, biotite, and hornblende, and a porous
glassy groundmass. The main phenocryst is quartz, which is very
fresh and generally shows crystal outlines. Orthoclase and plagio-
clase are present, but not abundant. Most of them have suffered
surface alteration. The biotite is frequently twinned and has inclu-
sions of apatite. Fragments of hornblende and pyroxene are present,
the latter being in included rock fragments. Magnetite particles
are scattered through the rock.

The groundmass is amorphous with numerous cavities filled or
lined with calcite. For this reason calcite forms quite a large per-
centage of the rock.

Biotite-hornblende-pyroxene andesite.—In the Swett Hills the bio-
tite-hornblende-pyroxene andesite bed consists of several types of
rock. In the western part there is at the base a dark hornblende
andesite breccia and above this several layers of rhyolite and tra-
chyte interlayered with limestone and conglomerate. In the eastern
part all but the breccia disappear, and a biotite-hornblende-pyroxene
andesite, which to the west only caps the lower series, makes up

almost the entire thickness. In the Harmony Mountains the formation consists of rhyolite, trachyte, and conglomerate, while in the lava area southwest of Iron Mountain only the hornblende andesite breccia is present, with a little limestone and conglomerate.

The biotite-hornblende-pyroxene andesite is a light pinkish-gray porphyritic rock, with feldspar as the main phenocryst. Biotite, hornblende, and diopside are of equal importance. Quartz and magnetite are present. The feldspars are mainly labradorite, but a little orthoclase is present. They show zonal growth and have inclusions of apatite. A few fragments of quartz are present. The diopside is light green in color, while the hornblende and biotite are dark brown and show alteration to ferrite. The groundmass is amorphous with finely crystalline feldspar and specks of ferrite.

The hornblende andesite breccia is a dark purplish-gray porphyritic rock, with phenocrysts of brown hornblende and a groundmass of small lath-shaped crystals of labradorite, orthoclase, monoclinic and rhombic pyroxene, separated by irregular cavities. The rhyolite and trachyte layers have the same texture as the underlying tuffaceous rhyolite and trachyte formations. The limestones and conglomerate are like those of the Tertiary, but thinner and less consolidated. Their presence in the uppermost lava formation shows that all the lavas were submerged after its deposition.

CHEMICAL AND MINERAL COMPOSITION OF THE IGNEOUS ROCKS.

Analyses have been made of the intrusive andesite and of the four principal flows, namely, the early trachyte (1), early rhyolite (2), latest trachyte (5), and dacite (7). Of the rest of the flows, some, while they have considerable horizontal distribution, are very thin, while the others are local in their distribution.

The following table gives the chemical composition, the approximate mineral composition of the same specimens determined from thin sections, and the mineral composition of the same specimens calculated as modes from the chemical composition for each of these formations, in order of age:

Analyses of igneous rocks from Iron Springs district.

CHEMICAL COMPOSITION.

	A.	B.	C.	D.	E.	E'.	F.	G.
SiO_2...	65.29	63.63	64.83	58.04	66.38	70.03	73.17	61.05
Al_2O_3...	11.57	15.64	16.68	18.96	13.72	14.47	13.34	16.03
Fe_2O_3...	2.10	3.59	3.74	5.88	2.23	2.35	1.35	5.42
FeO...	2.67	.93	1.22	1.33	.80	.84	.76	.98
MgO...	2.87	2.32	.79	1.11	.54	.57	.81	3.03
CaO...	4.85	4.46	2.85	6.12	5.49	2.42	5.40	5.40
Na_2O...	2.10	1.70	.86	2.26	2.50	2.64	1.80	1.43
K_2O...	5.18	5.22	7.56	4.08	5.20	5.48	7.10	5.58
H_2O+...	2.32	2.10	.92	2.05	.92	.97	.54	.81
P_2O_5...	.22	.15	.35	.34	.08	.08	.07	.30
CO_2...	...	...	...	...	2.52	...	...	...
BaO...	.17	.05	.11	.04	.11	.11	.10	.08
	99.34	99.79	99.91	100.21	100.49	99.96	100.36	100.11

MINERAL COMPOSITION DETERMINED FROM THIN SECTIONS.

	A.	B.	C.	D.	E.	F.	G.
Quartz...	Some...	Some...	...	Some...	Much...	Some...	Some.
Orthoclase...	Some...	Some...	Some...	Some...	Much...	Some...	Much.
Plagioclase...	Much...	Much...	Little...	Much...	Little...	Little...	Much.
Biotite...	Some...	Some...	Little...	Little...	Some...	Some...	Some.
Hornblende...	Some...	Little...	...	...	...	...	Some.
Diopside...	Little...	Little...	...	Little...	...	...	Some.
Magnetite...	Little...	Little...	Little...	Little...	Little...	Little...	Little.

MINERAL COMPOSITION CALCULATED FROM CHEMICAL COMPOSITION.

	A.	B.	C.	D.	E.	F.	G.
Quartz...	23.52	22.26	22.02	15.06	27.60	33.12	19.38
Orthoclase...	28.35	27.80	43.37	22.79	28.35	39.47	28.35
Albite...	14.67	13.10	7.34	18.86	20.96	15.19	12.05
Anorthite...	5.84	15.29	11.12	25.85	10.56	5.56	15.84
Biotite [a]...	5.08	4.63	3.81	3.71	3.70	2.70	2.70
Phlogopite [a]...	...	...	...	...	...	1.62	4.16
Hornblende [a]...	5.89	1.99	...	...	...	...	...
Diopside...	6.03	4.32	.86	2.16	...	...	7.12
Magnetite...	1.39	1.16	1.85	2.78	1.62	.92	1.85
Apatite...	.31	.31	.62	.62	.31	.31	.62
Limonite...	...	2.24	...	.75	4.11	.56	.75
Hematite...	...	...	1.28	...	...	...	3.52
Calcite...	...	...	...	...	5.70	...	...
Kaolin...	...	3.78	5.16	3.09	...	...	3.61
Serpentine...	2.48	1.84	...	...	...	...	...
Water...	1.90	.90	...	.97	.76	.34	...
Sillimanite...	...	...	1.45	...	...	...	...
Wollastonite...	3.48	...	...	...	...	...	...
	98.94	99.62	99.63	100.00	100.12	99.98	99.95

[a] Composition based on average of analyses in Dana's Manual of Mineralogy.

A. Specimen 46612. Fresh intrusive andesite east of Granite Mountain. Analysis by R. D. Hall, University of Wisconsin.
B. Specimen 46377. Slightly weathered intrusive andesite from Desert Mound. Analysis by R. D. Hall, University of Wisconsin.
C. Specimen 46533. Fresh early trachyte from Antelope Range (No. 1 of flows). Analysis by R. D. Hall, University of Wisconsin.
D. Specimen 46584. Andesite from same formation as specimen C north of Stoddard Mountain. Analysis by R. D. Hall, University of Wisconsin.
E. Specimen 46521. Early rhyolite from Eightmile Hills (No. 2 of flows). Analysis by R. D. Hall, University of Wisconsin.
E'. Specimen 46521. Early rhyolite. Recalculated on the basis of 100 per cent after removing CaO and CO_2 of the infiltrated calcite.
F. Specimen 46557. Latest trachyte from Antelope Hills (No. 5 of flows). Analysis by R. D. Hall, University of Wisconsin.
G. Specimen 46586A. Dacite from Swett Hills (No. 7 of flows). Analysis by R. D. Hall, University of Wisconsin.

Partial chemical analyses of igneous rocks from Iron Springs district.

[Analyst, Fred Lerch, Biwabik, Minnesota.]

	H.	I.	J.	K.	L.	M.	N.
SiO_2	53.65	66.20					
Al_2O_3	1.59	2.72					
P_2O_3	.118	.117	.076	.138	.192	.090	.087
Fe	5.65	3.71	4.56	5.58	6.49	4.91	5.16

	O.	P.	Q.	R.	S.	T.	U.
P_2O_3	.133	.060	.074	.040	.032	.124	.127
Fe	5.79	2.43	2.29	2.78	1.74	4.03	4.24

H. Specimen 46317. Intrusive andesite. Three Peaks.
I. Specimen 46318. Same.
J. Specimen 46500. Early trachyte. Eightmile Hills.
K. Specimen 46533. Same. Antelope Range.
L. Specimen 46540. Same.
M. Specimen 46541. Same.
N. Specimen 46547. Same.
O. Specimen 46584. Same. North of Stoddard Mountain.

P. Specimen 46502. Early tuffaceous rhyolite. Eightmile Hills.
Q. Specimen 46503. Same.
R. Specimen 46476. Latest trachyte. Swett Hills.
S. Specimen 46477. Same (pitchstone at base).
T. Specimen 46504. Biotite dacite. Eightmile Hills.
U. Specimen 46380. Same.

Analyses A and B are average andesites, although A is a little too high in potash and low in alumina. C is a typical trachyte, while D is an andesite forming a subordinate part of the early trachyte bed.

The early rhyolite (E) is too high in lime, owing to secondary calcite occurring in amygdules. This has been subtracted from the analysis and the latter recalculated to 100 per cent. This recalculated composition (E') is that of a typical rhyolite. The composition of F, as given in the table, is too high in silica and too low in alumina for a trachyte. The excess silica is accounted for by secondary infiltration in amygdules, and if this be removed and the composition recalculated to 100 per cent the alumina percentage will be brought up within the limits. The lack of quartz phenocrysts determines its name.

The dacite (G) is too low in silica for a typical dacite, but the presence of quartz phenocrysts determines its name.

According to Professor Iddings the presence of trachyte and andesite in the same group of lavas is a rare occurrence, nevertheless chemical and mineral compositions indicate that both probably occur in the Iron Springs area.

The analyses represent the general acidic character of the series and show a slight range in chemical composition, especially in the silica and alkalies. Silica ranges from 58 to 70 per cent, the increase to 73 per cent in analysis F being due largely to the later cavity fillings. The alkalies range from $6\frac{1}{2}$ to 9 per cent, the potash being in excess of the soda in all cases. This excess reaches a maximum in the trachytes C and F, a fact well illustrated in the mineral composition

tables by the excess of potash feldspar over lime-soda feldspar in these rocks.

The alkalies vary approximately with the amount of silica, as follows:

Variations in alkali and silica in igneous rocks of Iron Springs district.

	F.	E.	A.	C.	B.	G.	D.
SiO2	73.17	70.03	65.29	64.83	63.63	61.05	58.04
Alkalies	8.90	8.12	7.28	8.42	6.92	7.01	6.34

The only striking exception to this rule is "C," which is high in alkalies and comparatively low in silica.

The total alkalies vary inversely as the lime with minor exceptions.

Variations in alkali and lime in igneous rocks of Iron Springs district.

	F.	C.	E.	A.	G.	B.	D.
Alkalies	8.90	8.42	8.12	7.28	7.01	6.92	6.34
CaO	1.32	2.85	2.42	4.85	5.40	4.46	6.12

An increase in the amount of silica and alumina is attended by a decrease in iron, magnesia, and lime, illustrated in the following table:

Variations in silica and alumina corresponding to variations in iron, magnesia, and lime in igneous rocks of Iron Springs district.

	F.	E.	C.	B.	G.	D.	A.
SiO2 and Al2O3	86.51	84.50	81.51	79.27	77.08	77.00	76.86
Fe2O3 FeO, MgO, and CaO	4.24	6.18	8.60	12.30	14.83	14.94	12.49

The relation between the potash and soda is similar to that shown by Professor Pirsson to exist in the rocks of the Highwood Mountains,[a] but the relation between the alkalies and the lime is reversed. The definite relation existing between potash, soda, and lime in the Highwood rocks, according to Professor Pirsson, must have been characteristic of the parent magma, and separates these rocks from rocks of other areas and groups them into a clan. The same argument may be applied to the rocks of the Iron Springs district.

The chemical character of the rocks is clearly expressed by the mineral composition. The predominance of potash is indicated by an abundance of orthoclase, while the basic feldspar varies in amount with the lime, except in the early rhyolite (E), in which the high

[a] Pirsson, L. V., Petrography and geology of the igneous rocks of the Highwood Mountains, Montana: Bull. U. S. Geol. Survey No. 237, 1905, pp. 172-174.

lime percentage is accounted for by the presence of infiltrated calcite. In analyses C, D, E, and F the low magnesia explains the absence of hornblende and diopside and the lowering of the biotite percentage.

The mineral compositions calculated from the analyses (p. 58) are in general similar to those observed, yet on account of fine-grained or amorphous groundmass the mineral composition as determined from thin sections could only be approximate and in some instances does not correspond well with the calculated modes, the greatest discrepancy being in the relative amounts of quartz, ortho-clase, and lime-soda feldspar. Where the groundmass is crypto-crystalline, the mineral composition is based on the phenocrysts. In the dacite and andesites these form a large percentage of the mass of the rock, while in the early trachytes, the early rhyolite, and the latest trachyte they are subordinate in amount. Sillimanite and wollastonite were not seen in the rocks, but were added to take up surplus alumina and lime.

RELATIONS OF LACCOLITHS AND EFFUSIVES IN GENESIS.

The question naturally arises whether or not the intrusive andesite and the effusives came from the same reservoir. The chemical com-positions of the laccolithic rocks and the different flows show but a small range. With very little differentiation all the different phases may have originated from the same parent magma. It is certain, however, that the laccoliths did not act as vents through which the outpouring of the effusives took place. The andesite had been intruded, solidified, and eroded when the lavas were poured out over the eroded edges of the uplifted sediments. That the lavas came to the surface through the laccoliths after their solidification and erosion does not seem likely, since the andesite areas show no dikes or stocks, unless the ore veins be so called. Neither are there stocks or dikes else-where in the district through which the eruptions might have occurred; hence we are driven outside of the area for the source of the effusives.

The following table shows an approximation of the average chem-ical composition of the lavas and andesite, obtained by averaging the preceding analyses. The general similarity of composition indicates that both may have come from the same reservoir.

Average chemical composition of laccoliths and effusives.

	Laccoliths.	Effusives.		Laccoliths.	Effusives.
SiO_2	64. 46	66. 42	K_2O	5. 20	5. 99
Al_2O_3	13. 60	15. 41	H_2O+	2. 21	. 95
Fe_2O_3	2. 85	3. 48	P_2O_5	. 18	. 19
FeO	1. 80	. 96	BaO	. 11	. 09
MgO	2. 59	1. 34			
CaO	4. 65	3. 40		99. 55	100. 09
Na_2O	1. 90	1. 86			

CHAPTER V.

CORRELATION.

SEDIMENTARY ROCKS.

Several excursions were taken into the surrounding country for the purpose of correlating the formations of the Iron Springs district with those of the Colob Plateau, one of the High Plateaus of Utah, and with the Pine Valley Mountains.

The rocks of these areas were first studied in 1871, 1872, and 1873 by G. K. Gilbert, A. R. Marvine, and E. E. Howell for the Wheeler Survey.[a] In 1875, 1876, and 1877, they were studied by Maj. C. E. Dutton[b] for the Rocky Mountain Survey and again in 1880 for the United States Geological Survey in connection with the work in Grand Canyon. In the summer of 1902 a small area east of the Pine Valley Mountains along the west margin of the High Plateaus was mapped by E. Huntington and J. W. Goldthwait,[c] under the direction of Prof. W. M. Davis, of Harvard University.

Dutton[d] classified the rocks of this region into systems from Carboniferous to Quaternary. Huntington and Goldthwait[e] subdivided the larger division of Dutton to some extent, and applied geographic names. The following tables show the correlation of the rocks of the Iron Springs district with those given by Huntington and Goldthwait and by Dutton:

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[a] Gilbert, G. K., Report on the geology of portions of Nevada, Utah, California, and Arizona, examined in the years 1871 and 1872: U. S. Geog. Surv. W. 100th Mer., vol. 3, Geology, pt. 1, 1875, pp. 17-187. Marvine, A. R., Report on the geology of route from St. George, Utah, to Gila River, Arizona, examined in 1871: U. S. Geog. Surv. W. 100th Mer., vol. 3, Geology, pt. 2, 1875, pp. 189-225. Howell, E. E., Report on the geology of portions of Utah, Nevada, Arizona, and New Mexico, examined in the years 1872 and 1873: U. S. Geog. Surv. W. 100th Mer., vol. 3, Geology, pt. 3, 1875, pp. 227-301.

[b] Dutton, C. E., Report on the geology of the High Plateaus of Utah: U.S. Geog. and Geol. Surv. Rocky Mtn. Region, 1880, pp. 307; Tertiary history of the Grand Canyon district: Mon. U. S. Geol. Survey, vol. 2, 1882, pp. 264.

[c] Huntington, Ellsworth, and Goldthwait, J. W., The Hurricane fault in the Toquerville district, Utah: Bull. Mus. Comp. Zool., Harvard Coll., No. 42 (Geol. Ser., vol. 6), 1904, pp. 199-259.

[d] Dutton, C. E., op. cit.

[e] Op. cit., pp. 202-208.

Correlation of rocks of the Iron Springs district with rocks of the Colob Plateau.

Colob Plateau.		Iron Springs district.
Huntington and Goldthwait.	Dutton.	
Basalt.	Quaternary sand, gravel, and clay. Basalt.	Quaternary sand, gravel, and clay.
Pleistocene gravels.		Pleistocene conglomerate.
Trachyte, andesite.	Andesite, trachyte, rhyolite.	Andesite, trachyte, rhyolite, etc.
Tertiary limestone, shale, and conglomerate.	Tertiary limestone, shale, and conglomerate.	Claron limestone, including some sandstone and conglomerate.
Cretaceous sandstone, shale, and limestone.	Cretaceous sandstone, shale, and limestone.	Pinto sandstone, including some shale, conglomerate, and limestone lenses.
Colob sandstone.	Jurassic shale. Jurassic sandstone.	(?)
Kanab sandstone. Painted Desert sandstone and shale. Shinarump conglomerate.	Triassic sandstone, shale, and conglomerate.	(Missing.)
Moencopie shale and sandstone.	Permian shale and sandstone.	(Missing.)
Super-Aubrey shale and limestone. Aubrey limestone.	Carboniferous limestone.	Homestake limestone.

The fossils found in the Homestake limestone are few and poorly preserved. They were referred for determination to Prof. Eliot Blackwelder, of the University of Wisconsin, and Dr. George H. Girty, of the United States Geological Survey. Professor Blackwelder determined some of the better preserved forms as *Aviculopecten*, a genus ranging from Silurian to Triassic, but here probably Carboniferous. Doctor Girty says:

> The specific determination of these forms is hardly possible from the imperfect condition of the material. . . . I believe that should you obtain more complete collections they would prove that the beds from which they were obtained should be correlated with that portion of the Wasatch Mountains section which the geologists of the Fortieth Parallel Survey designated the Permo-Carboniferous. This is likely to be the highest Paleozoic horizon found in your region.

The overlying Pinto formation is satisfactorily determined as Cretaceous. The Homestake limestone could not be Jurassic, according to its fossils, and since the limestone is dissimilar to the Triassic and Permian sediments of the adjacent High Plateaus, which are masses of sandstone and shale, it is referred to the next preceding period, the Carboniferous. Specific correlation with the Aubrey (Carboniferous) limestone naturally suggests itself, but it differs much from the latter in appearance and lithologic character, in that it is more sandy, shows bedding plainly, and is yellow, while the Homestake limestone is a pure, massive, dark-blue-gray limestone, lacking a conspicuous bedding.

So far as known, the Pinto sandstone of the Iron Springs quadrangle bears no fossils, but in the southern part it contains a few layers of carbonaceous shales, which were followed southward and connected with the anthracite beds of Stoddard Mountain (mapped by the Wheeler Survey as Cretaceous and correlated by that survey with the Cretaceous rocks on the Colob Plateau), which contain numerous workable seams of bituminous coal, associated with oyster beds often several feet in thickness. The lower part of the Pinto formation may be Jurassic, but no evidence for the separation could be found.

The Claron formation contains only a few fossils and these are Carboniferous forms in pebbles in the conglomerates. They are of value only in pointing to a Carboniferous limestone outside of the district as the source of the conglomerates. Nevertheless, the Claron formation may be satisfactorily correlated with the Tertiary of Dutton,[a] which is the Uinta formation of Smith,[b] on the Markagunt Plateau. At the head of Cedar Canyon (Coal Creek valley), cutting the Markagunt Plateau, there are 3,000 feet of many-colored Tertiary limestones, sandstones, and conglomerates. The limestone of the Cedar Canyon Tertiary and of the Claron were found to be much the same both in regard to general appearance and lithology. Both are many colored, although red predominates, and both are sandy. The cherty concretions described above are also characteristic of many layers in both areas. The Claron formation of the Iron Springs district contains more fragmental material in the form of beds of conglomerate, but this is to be expected, because it is nearer the shore line of the Eocene lake supposed by Smith to lie west of the High Plateau region. The Uinta formation is supposed to have been deposited in a fresh-water lake basin, which during the early stages of deposition extended into southwestern Utah nearly to the Nevada and Arizona boundaries but gradually retreated northeastward into central Utah. The lower part of the Cedar Canyon Tertiary was not seen. It may contain more beds of conglomerate than the middle and upper parts, and hence this part might be more specifically correlated with the Claron formation of the Iron Springs district.

In general, then, the correlation of the Cretaceous and Tertiary rocks of the Iron Springs district is based on similarity in lithology, thickness, and succession of the Pinto and Claron formations with the Cretaceous and Tertiary series, respectively, of the High Plateaus beginning 15 miles to the east, and on the direct connection of the Pinto formation with the Cretaceous coal-bearing beds of Stoddard Mountain. The assignment of the underlying Homestake formation to the Carboniferous is based on obscure fossil forms and

a Op. cit.   b Smith, J. H., The Eocene of North America: Jour. Geol., vol. 8, 1900, p. 452.

on the fact that, though differing lithologically from the Aubrey limestone (Carboniferous) of the High Plateaus, it is more like it lithologically than any other formation underlying the Cretaceous of this region. A possible hiatus between the Pinto formation (Cretaceous) and the Homestake limestone (see p. 17) may account for the absence of Permian, Triassic, and perhaps Jurassic sediments—if the last named, indeed, be absent (see p. 16)—between the Cretaceous and Carboniferous of this district. The weak features of the correlation are the absence of sufficient fossil evidence, the dissimilarity of the Homestake and Aubrey formation, and the absence of Permian, Triassic, and Jurassic sediments with so slight a structural discordance.

IGNEOUS ROCKS.

Only the earlier trachyte and the tuffaceous rhyolite have been correlated with rocks previously studied outside of the district, namely, the "rhyolite" of Dutton's High Plateaus survey.[a] These rocks were examined on Brian Head, near the south end of the area mapped by Dutton as rhyolite, and were found to be composed of a considerable thickness of rhyolite underlain by a rather thin layer of dark scoriaceous material like some of the scoriaceous phases of the earlier trachyte of the Iron Springs district. Below this, as in the Iron Springs district, were found Tertiary limestones and conglomerates. Thus a general correlation with the lavas may be made on the basis of their superposition above the Tertiary limestones and conglomerates in the two districts.

[a] Dutton, C. E., Report on the geology of the High Plateaus of Utah: U. S. Geog. and Geol. Surv. Rocky Mtn. Region, 1880, pp. 61 et seq.

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CHAPTER VI.

DESCRIPTION OF THE IRON ORES.

DISTRIBUTION, EXPOSURES, AND TOPOGRAPHY.

The iron ores occur in disconnected masses within a general area about 1½ miles wide by 20 miles long, running northeast and southwest through the district mapped. (See Pls. II, XV, XVI.) They lie for the most part on eastern and southern slopes or foothills of The Three Peaks, Granite Mountain, and Iron Mountain, between elevations of 5,600 and 6,700 feet, but some of them, as on Iron Mountain, appear at or near the tops of the mountains at elevations between 7,000 and 8,000 feet.

Some of the iron-ore exposures stand out as much as 200 feet above the surrounding country as black, jagged ridges (Pls. XVII, B, to XIX, A). Others, including several of the larger deposits on the lower slopes, do not stand above the surrounding rocks (Pl. XIX, B), but are known by isolated exposures and black iron-formation fragments disseminated in the loose detrital material at the surface. Some of the ore does not appear at the surface at all, being covered by andesite detritus washed from the upper slopes, though, even here, fragments of ore are likely to appear in the detritus farther down the slopes. In such places the exact shape and distribution of the deposits can not be determined without trenching or pitting. Fortunately such work will suffice fairly well throughout the possible ore-bearing areas, though there are places where areal extensions of iron-ore belts may be found by underground exploration, or where belts, mapped as continuous on the basis of the surface fragments, may really be discontinuous. The deepest pits in the district, 130 feet, have not yet reached water level.

GEOLOGICAL AND STRUCTURAL RELATIONS OF THE ORE DEPOSITS.

The ore deposits for the most part lie at or near the contact of the andesite laccoliths and the Homestake limestone. Some of them occur entirely within the andesite well up the slopes, and others entirely within the limestone, but seldom far from the contact. (See Pls. III–V, pocket.)

N

SEC. 18

SEC. 8

SEC. 4

SEC. 17

SEC. 9

SEC. 3

BLACKBIRD
57

SEC. 19

BERT MINE
NO.6
4940

SHORT LINE
MINE
5089

SHORT LINE
NO.1 5089

SHORT
LINE
NO.4 5089

NO.1

NO.2

NO.3

POLAR NO.5
4890

POLAR NO.6
4890

POLAR NO.7
4890

POLAR NO.8
4890

SHORTLINE
LEDGE
5089

SHORT LINE
NO 2 5089

SHORTLINE
NO.3
5089

MAMMOTH
EXTENSION
5089

MAMMOTH IRON
5089

MAMMOTH
MINE

MAMMOTH
IRON
NO.1 5089

MAMMOTH
IRON
No 5089

MAMMOTH
IRON
5089

McCARRY
50

BIG JIM
5089

KING NO 5
5089

HOPE
5089

MASSACHUSETTS
5089

CRACKER
JACH
5089

SEC. 16

CONTACT
NO.1
5089

KING
5089

LITTLE
JIM
5089

KING NO
5089

ROOSEVELT
5089

IMPERIAL
5089

SEC. 10

CONTACT
NO 2
5089

DESERT
5089

TWITCHELL
56

ECLIPSE
55

VERMILLION
10

CONTACT
NO 3
5089

CON-
STOCK

MOUNTILA

TARANTULA
4908

SEC. 20

PIOCHE
51

GREAT
WESTERN
45

SEC. 21

RATTLER
5089

RATTLER
EXTENSION
5089

S. B. MILLER

RATTLER
NO 3
5089

RATTLER
NO 4

LITTLE
MORMON
52

RATTLER
NO 5

T. 35 S., R. 12 W.

SEC. 30

SEC. 15

T. 36 S., R. 13 W.

SEC. 31

SEC. 29

SEC. 44
SHARP IRON

WAR EAGLE
47

SMITH
39

LINDSEY

IRONCLAD
56

SEC. 28

SMITH
PLACER

56
MARSHALL

SEC. 22

ADAMS 40

SEC. 1

SEC. 6

WALKER
43

4799

SOUTHERN
31

SOUTH
STAR

LITTLE
FALLS

CUBA
NO.1
4797

SEC. 32

T. 36 S., R. 12 W.

SEC. 33

SEC. 27

0   1/2   1   2 miles

MAP OF MINING CLAIMS IN THE DESERT MOUND AND IRON SPRINGS AREAS, IRON SPRINGS DISTRICT.

Adapted from map by Alfredo R. Talamantes, 1903.

MAP OF MINING CLAIMS OF THE IRON MOUNTAIN AREA, IRON SPRINGS DISTRICT.

Adapted from map by Alfredo R. Talamantes, 1903.

ORE DEPOSITS IN ANDESITE.

The deposits within the andesite appear at the surface in long, narrow bands, ranging from 20 feet down to less than 1 foot in width, and usually standing from a few feet to 20 or 30 feet above the adjacent andesite. (Pl. XVIII, A.) These are true veins or fissure deposits. The fissures which they fill are usually somewhat curved, tapered at one or both ends, are almost invariably branching, and are accompanied by subsidiary parallel fissures. (See Pl. III.) Their orientation is diverse; in general they follow the directions of the adjacent jointing and faulting.

ORE DEPOSITS AT ANDESITE-LIMESTONE CONTACT.

The larger and more numerous deposits are along the andesite-limestone contact. (Pls. III, V, and XVII, A.) As exposed in the erosion surfaces they are commonly lens shaped, with their longer diameters parallel to the contours of the hills, but from this there are important variations toward irregular polygonal shapes, due partly to faulting and partly to the variation in the angle between the erosion surface and the plane of the andesite-limestone contact which the ores follow. The deposits at the contact have as a hanging wall either the fresh limestone or the silicated phase characteristic of the contact with the andesite. The ore protrudes irregularly into the limestone in large and small masses and veins. Small masses of the ore, measuring from a few inches to a few feet, may be seen entirely within the limestone, and in turn fragments of limestone are found in the ore. Along fault planes the limestone is brecciated and cemented by ore. Notwithstanding this local irregularity, measured by inches and a few feet, the contacts on a large scale are usually even and continuous. The dip of the contact of the ore and the hanging wall is almost invariably steeper than the dip of the bedding of limestone; that is, almost vertical but with a slight dip away from the andesite, so far as can be determined from the sections exposed.

The foot wall of the ore is principally andesite, but at many localities the ore is separated from the andesite by a thin layer of the silicated contact phase of the limestone or the sandy basal phase of the limestone. The contact of the ore with the foot-wall andesite as a whole is considerably more regular than that with the hanging-wall limestone. There is less interpenetration of the two masses, yet occasional fragments of andesite protrude into the ore or are entirely surrounded by it, and andesite breccias with ore cement are not uncommon along faults. Andesite dikes or offshoots are rare in the ores and limestone near the contacts, but are known in one locality east of Iron Mountain. The andesite near the contact is altered to

a soft clay retaining andesite texture. The contacts may be vertical or inclined, but are commonly somewhat steeply inclined away from the andesite.

These simple relations of ore to wall rock, are complicated to a considerable extent by faulting, probably to a larger extent than has
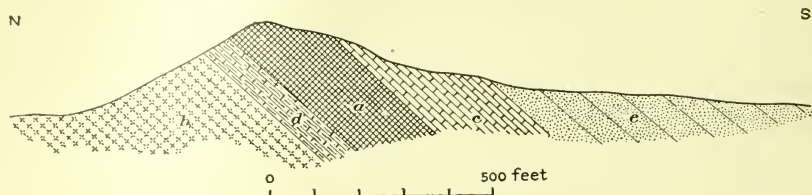
Fig. 4.—Cross section of Desert Mound contact deposit. *a*, Iron ore; *b*, laccolithic andesite; *c*, Homestake limestone; *d*, altered Homestake limestone; *e*, Pinto sandstone.

been proved. Because of the faulting the ore may be nearly or quite surrounded by andesite or by limestone or by any combination of these rocks. The map (Pl. II) indicates the effect of the faulting on the surface distribution. Its effect is probably equally marked on the third dimension.
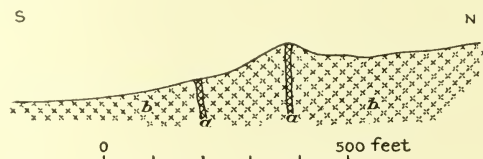
Fig. 5.—Cross section of Great Western fissure veins. *a*, Iron ore; *b*, laccolithic andesite.

The faulting is in considerable part earlier than the ore deposition, as shown by the fact that the fault breccias are cemented by ore. The Desert Mound and the Marshall claim in The Three Peaks area afford good illustrations. Other faults are distinctly later than the deposition of the ore, as on the Chesapeake claim and others on the
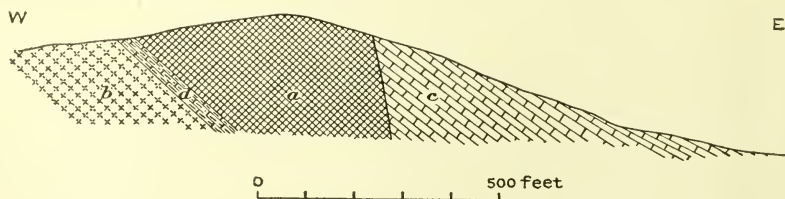
Fig. 6.—Cross section of Lindsay Hill contact deposit. *a*, Iron ore; *b*, laccolithic andesite; *c*, Homestake limestone; *d*, altered Homestake limestone.

slope and on the top of Iron Mountain. The earlier and the later faulting are not certainly to be distinguished in all places in the present state of development of the deposits, for the structural relations developed are in part similar in the two cases. The age of the late

A. SOUTHERN CROSS IRON-ORE DEPOSIT, EAST OF GRANITE MOUNTAINS, LOOKING NORTH.

The ore forms the summit and the dark area on the slope to the right and foreground.   The light area to the left is foot-wall andesite.   Hanging-wall sediments occupy the lower half of the slope to the right.

B. CHESAPEAKE IRON-ORE FISSURE VEIN, IRON MOUNTAIN.   (BOUNDED BY ANDESITE.)

faulting of the ore deposits is provisionally assigned to the postlava period, because this has been a period of considerable faulting throughout the district.
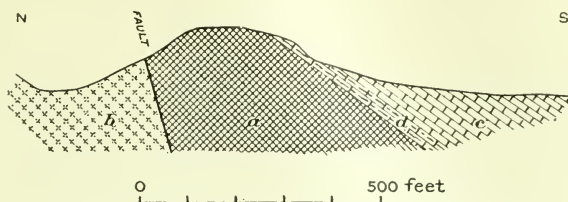
FIG. 7.—Cross section of Blowout contact deposit. *a*, Iron ore; *b*, laccolithic andesite; *c*, Homestake limestone; *d*, altered Homestake limestone.

The shape of the deposits in vertical cross section is incompletely known because exploration has been shallow. Available informa-
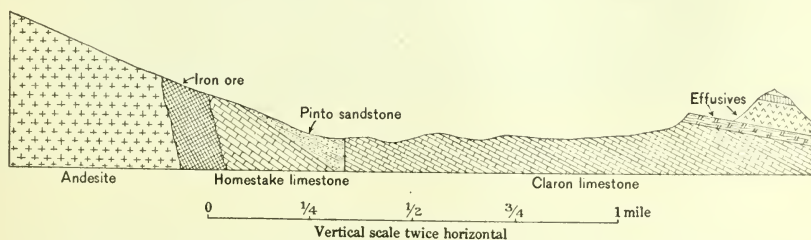
FIG. 8.—Cross section southeastward through Lindsay Hill, showing structural relations of ores.

tion is summarized in figs. 4, 5, 6, 7, 8, and 9. Inferences drawn from the manner of development of the ore are discussed on pages 76 and 85.
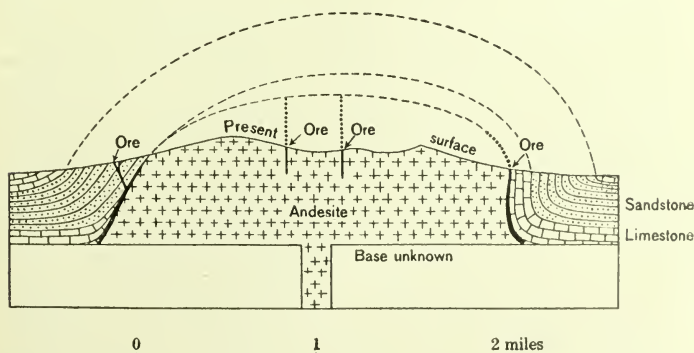
FIG. 9.—Ideal cross section through Iron Mountain laccolith, showing structural relations of ores.

ORE DEPOSITS IN BRECCIAS.

The ore constitutes cements or minute veins in fault breccias formed by the Homestake limestone, Pinto quartzite, or andesite at several localities, as follows: Limestone and quartzite at the Milner mine, Dear, Excelsior, Duluth No. 2, Desert Mound; andesite at the

Marshall, Blowout, Dexter, and Pot Metal claims. At the Desert
Mound a fault breccia crosses andesite, ore, and limestone, and mag-
netite constitutes breccia fragments.

The iron ores lack the associated "iron formation" of ferruginous
chert or jasper so characteristic of the Lake Superior iron ranges.
The nearest approach to jasper is in ores banded parallel to the walls
in the fissure veins in the andesite, and in contact ores with a banding
representing original limestone bedding.

The ore deposits nowhere come in contact with the later effusives.
However, it is a significant fact, to which attention will be directed in
discussion of origin of the ores, that the principal ore deposits are
approximately on the level of the general surface upon which the
lavas rest, sometimes above it but never below, and that the effusive
rocks before erosion must have rested upon the present deposits.
(See fig. 9.)

KINDS AND GRADES OF ORE.

The following description applies to the ores as they appear above
water level.   Pits have not yet been sunk below this depth.

The ore is mainly magnetite and hematite, usually intimately
intermixed, but locally segregated. So far as present information
goes (and it does not go far below the surface) the magnetite con-
stitutes about 70 per cent and the hematite 30 per cent of the whole.
As hematite appears more abundantly below the surface, it is thought
likely that deeper exploration will develop a higher percentage of
hematite.   At the surface the ore is ordinarily hard crystalline mag-
netite and hematite in porous, gnarled, and contorted masses, with
coarsely crystallized quartz and fibrous chalcedony as the principal
gangue mineral, filling, wholly or partly, cavities in the ore.   Other
gangue minerals occurring in small and practically negligible amounts
are apatite, mica, siderite, diopside, garnet, pyrite, chlorite, calcite,
barite, galena, amphibole, copper carbonates, limonite, and amethyst.
Of these minerals barite and galena are more closely associated with
the limestone than with the ore.   Melanterite, associated with pyrite,
was found in process of formation in the long tunnel on the Duncan
claim.   Beneath the surface the ore is usually softer and contains a
larger proportion of soft, bluish, reddish, brownish, grayish, and
greenish banded hematite, limonite, and magnetite in greatly varying
proportions and relations.   The gangue materials are more abundant
than near the surface, and calcite is in relatively increased proportion
as compared with the quartz.   The banding in the contact ores
partly represents the bedding of the limestone, which, as will be
shown later, the ore replaces.   Banding in the dike or vein ores in
the andesite is of unknown origin, possibly the result of original
deposition.   Some of the softer ore at lower levels entirely lacks
this banding.   Locally, as on the west side of Lindsay Hill, the

A. WAR EAGLE IRON-ORE DEPOSIT, NORTH OF IRON SPRINGS.
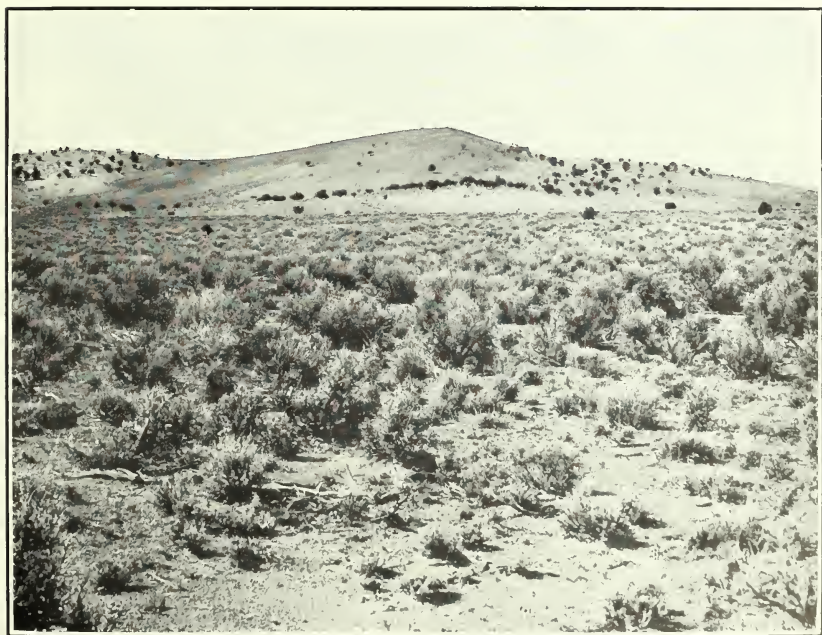
B. IRON-ORE CONTACT DEPOSIT AT DESERT MOUND, LOOKING WEST.

Iron ore forms the main hill. To the right is foot-wall andesite; to the left Homestake limestone. The lower slope in the foreground is composed of Homestake limestone and Pinto sandstone.

contact ore contains parallel streaks of a yellow clayey-looking material. On examination this resolves itself into a mixture of iron carbonate, iron sulphate, and glass, and probably some residual clay. Some of the narrow ore veins in the andesite possess a comb structure formed by the meeting and interlocking of apatite crystals projected from the walls (see fig. 10), sometimes not entirely closing the vein.

In the ore breccias the cements are magnetite, limonite, calcite, and quartz. At the Milner mine and elsewhere the magnetite has been deposited first about the fragments, here consisting of quartzite, then hematite, then limonite, but exceptionally in the same locality the reverse order appears.

The texture of the ore as a whole is good for furnace use. The harder ores will need crushing.
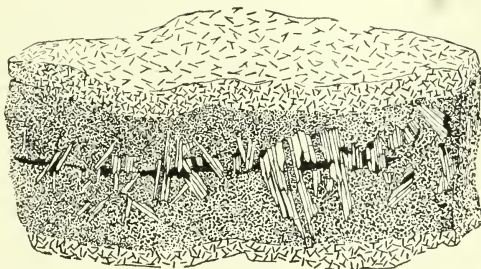
FIG. 10.—Vein of magnetite in andesite. The ore, indicated by the fine dots, does not quite fill the opening. Crystals of apatite penetrate the ore and interlock across the opening. One-half natural size.

For the following information concerning the composition of the ores the writers are indebted to Mr. Fred Lerch, of Biwabik, Minn., and to Mr. R. N. Dickman, of Chicago, Ill., both of whom have exhaustively sampled the ores of the district for commercial purposes. Corroborative figures were obtained from other commercial sources, and in a few cases analyses were made for the writers. In all, about 200 analyses from 400 samples of ores have been available, about two-thirds of them containing determinations only of iron, silica, and phosphorus, and one-third showing the percentages of all the common elements.

The average composition of the ores of the Iron Springs district, determined by combining all available analyses of the ores of the district from surface and pits, is as follows:

Average composition of iron ores of the Iron Springs district.

	Per cent.		Per cent.
Iron	56	Copper	0.027
Silica	7	Sulphur	.057
Phosphorus	.200	Manganese	.196
Lime and magnesia	4	Soda	1.19
Alumina	1	Potassa	.80
Water	3		

The samples run as low as 45 per cent in iron and as high as 69 per cent. The hard ore in the andesite runs higher on the average than the ore in the limestone. The ore at the surface, with few exceptions, has a higher percentage of iron than that below, the difference ranging from 3 to 12 per cent.

Phosphorus may diminish slightly in the deepest explorations, that is, below about 100 feet, but the distribution is so irregular and capricious that this generalization is doubtful. There are common variations within a short distance, both vertical and horizontal, of 0.050 to 3.18 per cent. A few 10-foot samples of ore run below the Bessemer limit in phosphorus, but practically all the ore as mined will be non-Bessemer ore.

Silica, averaging about 7 per cent, varies between 2 and 28 per cent, the lower figures being more common in the ore in the andesite. There is a distinct loss of silica at the surface, amounting to about 4 per cent as compared with that immediately below the surface.

Lime and magnesia range from 1.5 to 11 per cent. The hard ores in the andesite carry slightly less than the soft ores in the limestone. In both types the deeper ores carry the higher percentage. While both silica and lime are in greater quantity below the surface, corresponding to a lower percentage of iron, the lime and magnesia increase relatively faster than the silica with depth. Whereas at the surface a common ratio of silica to calcium and magnesium oxides is 2 to 1 by weight; below the surface it is more nearly 1 to 1.

Combined water varies from less than 1 per cent in the magnetite to 4 per cent in the soft ores, averaging about 3 per cent. One determination of moisture in crystallized magnetite[a] gives 0.45 per cent after heating to 110° C.

Sulphur is present in variable amounts, averaging .057 per cent, but in the deep exploration of one of the deposits, the Duncan, this figure is exceeded and the presence of sulphur becomes a serious consideration. There seems to be no general evidence of increase with depth, so far as exploration has yet gone, but water level has not yet been reached in the explorations.

Copper, titanium, and manganese are present, but not in injurious amounts.

Soda and potassa are determined in a single specimen.[b] Their significance is discussed on page 77.

Pl. XX summarizes the available information in regard to the variation of composition with depth.

A comparison of average analyses of Iron Springs iron ores with Lake Superior hematites and with the Clinton hematites of Alabama is made in the following table:

---

[a] Specimen 46113, Lindsay Hill. Analysis by R. D. Hall, University of Wisconsin.
[b] Specimen 46333A, Lindsay Hill. Analysis by R. D. Hall, University of Wisconsin
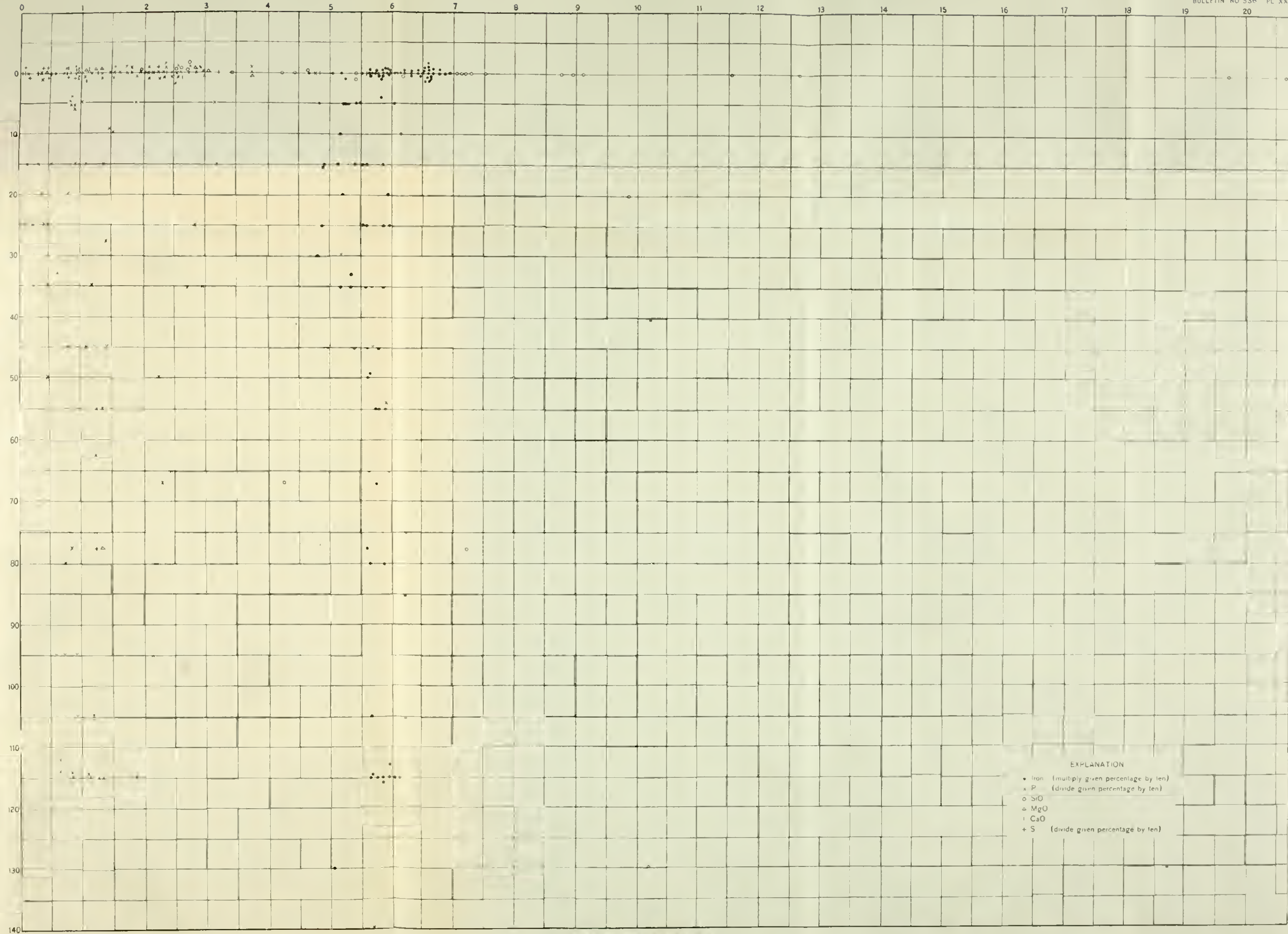
EXPLANATION

- Iron   (multiply given percentage by ten)
x P   (divide given percentage by ten)
o SiO
△ MgO
1 CaO
+ S   (divide given percentage by ten)

PLAT OF ORE COMPOSITION

Comparison of average analyses of Iron Springs iron ores with ores of Lake Superior and Alabama.

	Iron Springs ores.	Lake Superior ores.[a]	Alabama hematites.[b]
Iron (metallic)	56	59.6	37
Silica	7	7.5	13.44
Phosphorus	.200	.067	.37
Lime and magnesia	4	1.3	16.2
Alumina	1	1.5	3.18
Water, above 220°	3	4.0	.50
Copper	.027		
Sulphur	.057	.019	.07
Manganese	.196		
Carbonic acid			12.24

[a] Average cargo analyses for 1905.

[b] Birkinbine, John, The iron ores of Alabama (average analysis by Dr. William B. Phillips): Nineteenth Ann. Rept. U. S. Geol. Survey, pt. 6, 1898, p. 62.

It will be noted that the Iron Springs ores are intermediate in composition between the two other great classes of ores.

SIZE AND QUANTITY OF ORE DEPOSITS.

The iron-ore deposits vary from mere stringers to those having an area of 1,670,000 square feet. The aggregate surface of all the ore deposits of the district is 5,430,000 square feet or 0.2 square miles.

The aggregate tonnage of all grades of ore in the district, determined by multiplying the known area by the best available information as to depth in pits, drill holes, and erosion sections is 40,000,000 tons. The largest single deposit, figured on the same basis, has 15,600,000 tons. It is altogether likely that the figures are much too small rather than too large, because the depths used in the calculation have been those actually observed, and observation has not yet gone to the bottom. Inferences concerning the extension of the ore beneath the present workings, based on the manner of origin of the ore, are discussed on pages 87–89.

DEVELOPMENT.

During the years 1874 to 1876 a small furnace, with a daily capacity of 5 tons, was built and operated at Iron City, 5 miles southwest of Iron Mountain. The product was taken to the then prosperous silver mining camp at Pioche, Nev., and to Salt Lake, Utah. Later the old stack was torn down and a new one, projected to take its place, never rose higher than the foundation. The coal was derived from the Harmony Mountains, 5 miles to the southeast. The ore used in this furnace was taken out of the Duncan claim, one of the southernmost exposures of ore in the Pinto groups of claims, from shallow pits and short tunnels near the surface.

From time to time since the discovery of the deposits, pits and tunnels have been sunk in the ore, principally to meet assessment

requirements, but partly to show up the ore bodies. Some of the more vigorous exploration was conducted during the years 1902 and 1903. The total number of pits sunk to date has been approximately 1,600, of which 30 have gone to a depth greater than 50 feet. The maximum depth has been 130 feet.

Diamond drills have been used only at the Desert Mound, where 5 holes have been sunk. The detailed results of this drilling have been withheld from the United States Geological Survey, though some of the cores have been examined.

A. CONTACT PHASE OF PINTO SANDSTONE WEST OF IRON MOUNTAIN.

B. RETICULATED IRON-ORE VEINS IN ANDESITE.

The dark bands are iron ore protruding on the weathered surface.

CHAPTER VII.

ORIGIN OF THE IRON ORES.

GENERAL.

The principal ore deposits, viz, those near the contact of the andesite and limestone, are partly replacements of limestone. The original bedding of the limestone has been preserved in the ore in a number of places, and there is gradation between the ore and the limestone. These deposits are also in part fillings of fissures in limestone or between limestone and andesite. Where ore occurs within the andesite it fills fissures. The source of the iron-bearing solutions is the same for the limestone replacements and for the vein fillings in the limestone and in the andesite, for their mineralogical and textural characters are the same and in a few cases they are actually connected. Several hypotheses as to this source have suggested themselves: (1) That the ore-bearing solutions were associated with the intrusion of the andesite as "igneous after-effects;" (2) that they were meteoric waters, cold, or heated by contact with the laccolith, acting after the laccolithic intrusions and before the eruption of the surface flows; (3) that they were hot solutions, magmatic or meteoric or both, connected with the late eruptives of the district, deriving the ores from the effusives or from the underlying rocks; (4) that they were cold meteoric waters later than the effusives; (5) that they were due to some combination of these sources. The source of the ore is best explained by the first hypothesis, but later concentrations of the ore have occurred in the order named.

CONCENTRATION AND ALTERATION.

DEPOSITION OF ORE FOLLOWING LACCOLITH INTRUSIONS AS IGNEOUS AFTER-EFFECTS.

INTRODUCTION OF THE ORE.

The general association of the ores with the andesite and their specific association with fissures and faults in the andesite and the immediately adjacent limestones, the nature of the ores and gangue materials, especially the primary association of magnetite with garnet, amphibole, pyroxene, mica, apatite, iron sulphide, and glass,

seem to allow of but one general interpretation, and that is that the ore-bearing solutions were hot, rising from a deep-seated source through fissures in the andesite now filled with ore, at a period closely following the crystallization of at least the outer part of the laccolithic mass.

That the ore was introduced after the hardening and crystallization of the andesite and not before is shown not only by its occurrence in clear-cut fissures in the andesite and by the metamorphism of the andesite near the ore, but also by the lack of anything in the nature of a basic edge in the andesite, by the lack of irregularity in its composition, by the absence of ore for considerable intervals along the andesite contact, and by the fact that the intrusion of the andesite metamorphosed the limestone in a clearly recognizable manner, recrystallizing it, decarbonating it, rendering it more siliceous, and indurated the Pinto sandstone to a quartzite spotted by the segregation of ferrous iron in the form of amphibole—all before iron was introduced.

The ore-bearing fissures within the andesite (see p. 67) are of a kind which results from cooling and stretching. They are curved, tapered, branching, and in parallel sets, some of them minutely parallel and anastomosing (see Pl. XXI, B). The contraction accompanying the crystallization of the lava may also account for the ore-bearing fissures and faults following the periphery of the andesite, and affords a good explanation for the occurrence of ores at the contact in lens-shaped masses with their longer diameters parallel to the contact. The crystallization of a laccolith the size of the Iron Mountain laccolith from a viscous or glassy condition would yield a radial shortening of 200 to 500 feet, depending on the depth assigned to the laccolith. The parting of the andesite from the limestone during cooling finds its analogue in the parting of a casting from the mold.

The association of the ores with heavy anhydrous silicates, characteristic of slow-cooling intrusions, eliminates the possibility of development from the later effusives, which develop at their contacts minerals of a different kind and association, listed on page 85.

It is thought likely that the ore, at least the part within the zone of observation, was originally deposited as magnetite rather than as sulphide. Had it originally been sulphide, the subsequent alteration to magnetite would scarcely have left unchanged the closely associated silicates. The magnetites are nowhere observed to pass down into sulphides, although the ground-water level has not been reached. Until it has been reached, statements regarding the sulphides must be regarded as tentative.

Assuming, then, in the absence of negative evidence, that the iron was deposited primarily as magnetite, the iron may be supposed

to have been carried as a ferrous compound of some kind, possibly chloride or carbonate or sulphate, and its deposition as magnetite required partial oxidation. At the time of the intrusion the covering of the laccolith was probably about 4,000 feet thick, which would give little opportunity for the entrance of oxygen from the air. The expulsion of the carbon dioxide from the limestone which preceded the deposition of the ore may also have aided in keeping out oxygen. The probable alternative source of the oxygen is that derived by the breaking up of the water. Ferrous chloride reacts with water at temperatures above 500° C., with the simultaneous development of magnetite, hydrochloric acid, and free hydrogen, as follows:[a]

$$3FeCl_2 + 4H_2O = Fe_3O_4 + 6HCl + H_2 + 77Cal._8$$
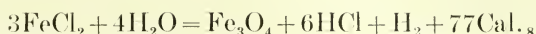
As magnetite is soluble in hydrochloric acid, there could obviously be no precipitation as long as this acid remained, but it is neutralized by the limestones which the solutions meet and the ore precipitated. Magnetite has abundantly replaced limestone in this district, as shown by the retention of the bedding structure of the limestone. Interchange of the ferrous iron with the lime would also precipitate the iron as iron carbonate, which is found associated with the magnetite. Had the iron been carried in ferric solution, limestone would have precipitated it as hematite. Possibly the hematite found in small amount in the ore may be so explained. Magnetite would also be precipitated by the evaporation and dispersion of the solution, which would result from the lowering temperature and pressure as the solutions left the andesite. Hydrochloric acid is easily volatilized with water, making it difficult to dehydrate a chloride without losing chlorine. So far as hydrochloric acid was lost, magnetite would be deposited. Kahlenberg[b] regards this process as entirely adequate to accomplish abundant precipitation of magnetite under the stated conditions. The existence of magnetite in dikes in the andesite or as cement in quartzite breccias, where limestone, as an alternative precipitating agent, is not present, is perhaps to be explained by this method of precipitation.

One of the conspicuous features of the contact metamorphism of the limestone and the metamorphism of the andesite adjacent to the ores is the introduction of soda. The ore of the first concentration itself shows a dominance of soda over potassa. These facts suggest that soda has been introduced not only into the limestone during its metamorphism but also later with the iron. It would be easy to explain the transportation of this salt in the chloride

[a] Moissan, Henri: Traité de chimie minérale, vol. 4, 1905, p. 330.
[b] Personal communication, Louis Kahlenberg, Univ. Wisconsin, 1907.

solution above hypothesized for the carrying of the iron. Lindgren finds salt in inclusions in vein quartz with a probable igneous origin. This most volatile of all the common mineral compounds is an abundant emanation product of volcanoes. It may be noted that sodium chloride would be decomposed by reaction with silicic acid undoubtedly met in the limestone contact, precipitating the sodium in its present silicate combination.

The introduction of apatite, garnet, amphibole, and pyroxene, all of them containing lime, and the greater abundance of these minerals nearer the limestone than elsewhere, suggests reaction between the hot solution and the limestone. It is not certain, however, that the limestone was necessary as a precipitating agent for the reason that these minerals are also found in fissures in the andesite entirely away from the limestone. The deposition of silicates may equally well have been a function of the change of temperature of the solutions. The order of deposition of the principal minerals of this first concentration seems to have been: (1) Magnetite (and other oxides), pyrites, and amphibole, apatite, and garnet; (2) diopside.

Interlayered with the magnetite and closely associated with glass is amorphous iron carbonate, the genetic relations of which to the other minerals are not known.

SOURCE AND CONDITIONS OF THE ORE-BEARING SOLUTIONS.

Judging from records available elsewhere as to flow of meteoric waters with depth, the 4,000 feet of rock covering the laccolith probably prevented ready access of abundant meteoric waters. Such as were present in the rocks may have reached high temperatures adjacent to the laccolith, and may have aided in the ore-depositing processes. But that the principal source of the solutions was the hot andesite magma seems to be implied by the nature of the minerals deposited and their association, and manner of association, with the laccolith. These solutions were ejected after at least the outer parts of the laccolith had crystallized.

That the temperature of the solutions was high is clearly shown by the nature of the materials deposited. The temperature was above the critical temperature of water—365°—judging from experimentally determined temperatures necessary for the crystallization of certain silicates similar to those here found.[a] A temperature higher than the critical temperature is further indicated by the presence of glass in the ores locally. From the fact that the fusion of the contact phase of limestone probably took place at temperatures ranging upward from 1,000° (see p. 36) and that the ore is in veins in this

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[a] Allen, E. T., Wright, F. E., and Clement, J. K., Minerals of the composition $MgSiO_3$; a case of tetramorphism: Am. Jour. Sci., 4th ser., vol. 22, 1906, p. 399.

phase and does not replace it, it may be inferred that the ore-bearing solutions were introduced into the limestone after its temperature had fallen below 1,000°. There is nothing to show that the temperature of the wall rock may not have been much lower, but the introduction of the ore followed so closely that the presumption is that the temperature may not have been much below 1,000° C. The rock pressure above the laccolith, amounting at a maximum to the weight of 4,500 feet of rock, was sufficient to hold the solution in a liquid state at temperatures of less than 365°. The hydrostatic pressure, which was probably the only effective one, was sufficient to hold the solution in a liquid state below temperatures of 325° C.

It is concluded that the solutions were probably after-effects of the andesite laccolith intrusions.

It is perhaps better to refer the solutions vaguely to "after-action" than to attempt more specifically to indicate whether they have come from the andesite itself or from some deep reservoir common to the andesite and the solutions. The abundant presence of magnetite in the andesite—$3\frac{1}{2}$ to 4 per cent—as so-called "reaction rims" about biotite, and to a less extent about hornblende, suggests a possible connection between the andesite and the ore-bearing solutions. The occurrence of magnetite in these relations has been held by Washington[a] to indicate the instability of the biotite and hornblende under surface conditions and their breaking down into paramorphic magnetite and augite, the latter being less abundant about the biotite than about the hornblende, and thus unimportant or altogether lacking in the Iron Springs rocks. By others the magnetite rims have been explained as due to absorption (solution) by the surrounding magma. The abundance of hydrogen gas (see p. 81) suggests that the development of the magnetite has resulted from the breaking down of water. But whatever the origin of the rims, it is apparent that the separation of the magnetite has occurred late in the cooling of the andesite. It would simplify matters greatly if this segregation of magnetite could be shown to be definitely related in some way to the ore-bearing solutions coming out of the andesite, but the writers know of no way to do this.

CONCENTRATION OF ORE BY WEATHERING PRIOR TO ERUPTION OF TERTIARY LAVAS.

When erosion had uncovered the ore deposits, it is reasonable to infer that the same processes of concentration that may be observed to-day were effective. These are described on pages 82–84.

[a] Washington, H. S., The magmatic alteration of hornblende and biotite: Jour. Geol., vol. 4, 1896, pp 257–282.

CONCENTRATION UNDER THE INFLUENCE OF TERTIARY LAVAS.

Inference of the modification of the ores by contact of the late lavas is to be drawn from the topographic relations of the ores and lavas. The lavas at one time rested directly against the andesitic cores of the mountains, upon the eroded edges of limestones and other sediments, and upon the ores. The principal ore deposits on the lower slopes of the hills are exposed at about the same elevation as the lower part of the lavas. Erosion has cut the lavas back, so that they now fringe the ore-bearing areas. (See Pl. II.) The heated waters associated with the lavas flowed along the andesite slopes where the ores occur.

Under the influence of the lavas and accompanying solutions, limonite was dehydrated, limonite and hematite were deoxidized (a process easily brought about in the laboratory by passing steam over such ores) and all of the minerals were coarsely recrystallized, making the upper parts of the deposits nearest the lavas consist principally of coarsely crystallized magnetite and some hematite. Hot solutions from the lavas introduced new minerals into cavities in the ore then and previously formed. These minerals consist principally of quartz and chalcedony and to a subordinate extent of hematite, magnetite, siderite, limonite, chlorite, calcite, barite, galena, and the copper carbonates. The heavy anhydrous minerals of the early deep-seated concentration were not developed.

Immediately beneath the lavas at observed contacts with the Claron limestone, there has been introduced, obviously from the lava, an abundance of more or less iron-stained chalcedony, with a jaspery appearance, identical with that observed in the upper parts of the ore deposits. The lavas themselves contain abundant chalcedonic quartz, filling large and small cavities and also minutely disseminated through the rock so intimately as to suggest hot solutions accompanying and immediately following the cooling of the lavas.

To test the conclusion that the chalcedony, taken to be the chief contribution of the extrusions, was not really deposited from meteoric waters, determination was made of the gas content of the chalcedony associated with the ore, for which the writers are indebted to Rollin T. Chamberlin of the University of Chicago. This analysis is compared in the following table with analyses of gas content of the andesite of the Iron Springs district by Mr. Chamberlin, one of volcanic emanations by Fouqué, and one of crystalline rocks by Tilden.

Analyses of gas content of chalcedony associated with ore, of andesite, of volcanic emanations, and of the average of five crystalline rocks.

	A.	B.	C.	D.
H₂S	0.00	0.12		
CO₂	13.93	13.93	0.22	34.104
CO	11.26	18.18		
O₂	.00	.00	21.11	8.422
CH₄	4.00	3.63	.07	3.224
H₂	64.40	58.71	56.70	52.134
N₂	6.44	5.43	21.90	2.072
	100.03	100.00	100.00	99.958
Volume of gas per volume of rock	.82	.82		4.5

A. Specimen 46613. Chalcedony in ore. From Crystal claim, Iron Mountain, Iron County, Utah. Analysis by Rollin T. Chamberlin. 0° C. and 760 mm. pressure.

B. Specimen 46642. Andesite from Granite Mountain, Iron County, Utah. Analysis by Rollin T. Chamberlin. Same conditions.

C. Gaseous emanations from Santorin. Analysis by Fouqué. (Santorin et ses éruptions, p. 225.) When studied spectroscopically these gases were found to have traces of chlorine, soda, and copper.

D. Average of five crystalline rocks. Analysis by Tilden. (Chem. News, November 9, 1897.) Standard conditions.

The gases in the chalcedony associated with the ore are roughly similar in their proportions to those of igneous rocks and volcanic conditions and differ generally in their proportions from the gases of the atmosphere. The gas analyses therefore furnish corroborative evidence of the introduction of the chalcedony directly from the late lavas.

That iron was introduced into the underlying rocks by the hot lava solutions is shown by its intimate relations with the chalcedony in the jaspery phases at observed contacts of the lava and by its occurrence in crystalline masses with chalcedony, partly or wholly filling cavities in the ore. The lava masses themselves are locally rich in iron. In the Antelope Springs area samples of the lavas (not veins) run as high as 6.5 per cent metallic iron. A few veins of magnetite and hematite are found in the lavas, which may have come from late lava solutions or from meteoric waters acting subsequently. The microscope discloses reaction rims about the biotite (as in the andesite, p. 48) formed during and following the flow of the lavas. The segregation of iron salts in the magma is further demonstrated by schlieren in the groundmass of the lavas, some of them light colored and some of them darker colored owing to a higher content of iron, and still further by the occasional segregation of magnetite or siderite about amygdaloidal cavities, both as fillings and as segregations in the adjacent groundmass. It is easy to conceive that iron salts got into the aqueous solutions which were in the lava at this stage of the cooling.

The introduction of calcite, quartz, siderite, limonite, galena, barite, and copper carbonates from the lavas is well shown at Chloride Canyon, where immediately below the contact these minerals appear in veins or disseminated through the rock. Chlorite is not found

here, but is present elsewhere in the same associations and was probably also introduced by the lava waters.

So obvious and striking are the effects of the extrusion of the lavas upon the principal ore deposits of the lower slopes of the laccoliths that the question was raised in the field study whether this concentration could not have been the principal and perhaps the only one, but the evidence seems to be conclusive that the concentration under the influence of the Tertiary lavas was after all relatively slight. Limestones in contact with the lava, but away from the andesite, do not carry iron-ore deposits, although reddened and silicified by solutions from the overlying lava. The minerals (barite, galena, copper carbonates, etc.) deposited in the ore by these solutions are distinctly later than the main mass of the ore, which is intimately associated with heavy anhydrous silicates characteristic of deep-seated intrusions. The coarse recrystallization of the ore under the lava influence seems to be shallow and the recrystallized ore to be superposed upon ore of finer and softer texture.

It seems a reasonably safe conclusion that during and following the lava extrusions both hot meteoric waters and waters contributed by the lavas flowed down the andesite slopes, that they were intermingled, and that the results of their work are not to be closely discriminated. The contribution of minerals from the lavas, however, would seem to require emphasis on the effectiveness of the waters from them.

ALTERATIONS SUBSEQUENT TO TERTIARY ERUPTIONS.

Observation has not yet gone below water level, so that a comparison of the ores of the weathered and unweathered zones can not be made. In general the characteristics of the ore are determined by conditions other than weathering. However, the ores as a whole are more porous near the erosion surface than below in pits. There is less calcite above than there is below. It is inferred that there has been leaching of the calcite above and perhaps redeposition below. The calcite is partly in fine granular form, incrusting ore and rock surfaces, and is similar in appearance to carbonate seen about some of the old vents of hot springs in this district. The possibility is therefore suggested that the solution and redistribution of the calcium carbonate went on partly through the agency of warm waters during the period of the cooling of the lava. However, redistribution is yet going on, through the agency of cold meteoric water, with sufficient rapidity to incrust rapidly changing erosion surfaces.

The magnetite commonly alters to limonite and hematite, in thin incrusting films, not directly at the surface, but in the solution cavities and in fissures near the surface. This alteration seems to

be at a maximum near the contact of ores and the adjacent rocks at the surface. Iron sulphide is changed to limonite and melanterite, some of which is removed in solution. Iron carbonate alters to limonite.

Apatite has been altered to osteolite and leached in the upper parts of the ores to a very considerable extent. Frequently the entire crystal of apatite has disappeared, its former presence being indicated only by the shape of the cavity. Presumably this apatite is redeposited below. This does not necessarily mean that the ores beneath the surface will run higher in phosphorus than at the surface, for the reason that there may be concentrated at the present surface a large part of the phosphorus which has come from the erosion of the overlying materials—a relatively larger amount of phosphorus than has been leached from the present surface and carried farther down.

Erosion has cut down the ore deposits many feet, as shown by abundant ore débris on the slopes. The ore is fissured. Extreme temperature changes spall off considerable blocks bounded at the sides by fissure planes. The ultimate product is magnetic sand, abundantly found on the lower slopes. For most of the district this erosion has gone on much less rapidly in the ore than in the adjacent andesite and limestone, with the result that the ore stands up in conspicuous black masses above the surrounding rocks. In a number of places, however, as on the Vermilion, Lindsay, Enterprise, part of the Mount Lion group, Comstock, Sunbeam, Wellington, Queen of the West, Black Hawk, Pinto mine, Pinto Nos. 3, 5, and 6, Burke No. 5, Red Clouds, and Duncan No. 1 claims, the ore has been cut down flush with the surrounding rocks. In these places the ore is uniformly softer than where standing up in conspicuous crags. It may be that the hard crystalline surface ores, serving more or less as protecting caps, have been locally undermined and cut off, leaving the underlying softer ore unprotected, with the result that it is cut down fully as rapidly as the adjacent rocks.

There is no evidence that weathering contributed to the deposits any considerable amount of ore from adjacent rocks. During erosion the magnetic iron of the andesite is concentrated into magnetic sands, as is the magnetite derived from the disintegration of the ore deposits. If alumina be assumed to remain constant during weathering it will be apparent from the analyses of the andesite that a small percentage of iron has been lost. With this percentage of loss it would require the weathering of a mass 100 feet thick and 0.2 square mile in area to yield a million tons of 56 per cent ore.

Iron is only slightly leached from the limestone during weathering, all but a minute part remaining in the residual clay. The residual soil from the Homestake limestone has been removed and the ore

deposits lack clay characteristic of residual deposits. If the slight amount carried off during weathering be assumed to be available for the development of ore deposits, there seems to be no reason why limestone of this low percentage of iron should yield sufficient ore for ore deposits in the particular localities where they now occur and not in others where the limestone contains as much iron.

SUMMARY OF MINERAL ASSOCIATIONS OF ORES IN RELATION TO ORIGIN.

The first effect of the andesite laccolith intrusions was the development of the silicated contact phase of limestone containing the minerals of column 1 in the following table. Slightly later, veins containing much the same association of minerals cut andesite and limestone (column 3). About the same time came the introduction of ore-bearing solutions in veins both in andesite and limestone and also replacing limestone (column 2). The minerals deposited are much the same as those previously developed in the contact limestone, though albite and orthoclase, present in the contact phase, have not been found in the ore, while apatite and garnet are more abundant in association with the ores than elsewhere in the contact phase. So similar are the groups of minerals developed up to this point and so close their association that they can not be sharply separated. There can be little doubt that they are developed under no greatly varying conditions with insignificant time intervals. According to Lindgren's classification,[a] the minerals of these groups are characteristic both of products of aqueo-igneous solutions, like pegmatites, and of products of aqueous solutions, in the lower contact zone. Criteria do not seem to be available in the Iron Springs district for clearly separating the two classes. The evidence appears to indicate that they all result from the andesite intrusion, principally through the transfer of pneumatolytic vapors, but that in the limestone contact they are also developed by simple elimination of lime and magnesia, and the recrystallization of the residue.

Later, solutions from the lavas introduced another and clearly distinguishable group of minerals, listed in column 5. These are found principally near the contact of the lavas with the prelava erosion surface, and were developed, therefore, under essentially surface conditions. They correspond closely to the minerals listed by Lindgren[a] as characteristic of these conditions.

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[a] Lindgren, Waldemar, The relation of ore deposition to physical conditions, Econ. Geol., vol. 2, 1907, pp. 122–125.

Mineral associations of ores.

1.	2.	3.	4.	5.	6.	7.
Minerals developed in limestone at contact of andesite intrusive.	Minerals of first ore concentration under influence of andesite intrusive.	Minerals in veins in contact limestone and andesite.a	Minerals of late ore concentration under influence of effusives.	Minerals of same age and origin as 4 but occurring in late veins in limestones.	Minerals in veins and amygdules in lavas.	Weathering minerals.
Quartz......	Quartz......	Quartz......	Quartz, chalcedony, etc.	Quartz, chalcedony, etc.	Quartz, chalcedony, opal, etc.	
Calcite.......	Calcite.......	Calcite.......	Calcite.......	Calcite.......	Calcite.......	
Diopside.....	Diopside.....	Diopside.				
Andradite (?).	Andradite...	Andradite.				
Apatite (?)..	Apatite......	Apatite......	....	....	....	Osteolite.
Actinolite....	Actinolite....	Actinolite.				
Magnetite ...	Magnetite ...	Magnetite ...	Magnetite ...	Magnetite.		
Hematite....	Hematite....	....	Hematite....	....	Hematite....	Hematite.
Limonite....	....		Limonite....	Limonite....	....	Limonite.
Albite.						
Orthoclase.						
Wollastonite (?).						
Phlogopite...	Biotite......	Phlogopite.				
Serpentine.						
Kaolin.......	Kaolin.					Kaolin.
Andalusite.		Epidote.				
	Pyrite.......	....	....	Pyrite.		
	Titanite.					
			Chlorite.b			
			Copper carbonates.	Copper carbonates.		
			Siderite.	Siderite.		
				Barite.		
				Galena.		
				Chalcopyrite.		

a Slightly later than those of column 1 and of about the same age as ores, but containing no ore.
b Found in one locality to depth of 80 feet in porous ore, but probably still due to action of effusives.

CONCLUSIONS AS TO THE ORIGIN OF THE ORES.

If the foregoing reasoning is correct, the events leading up to the completion of the ore deposits in their present form are in outline as follows:

(1) Intrusion of andesite laccoliths in Paleozoic and Mesozoic sediments, with consequent tilting of the strata in quaquaversal manner about the laccolith and contact metamorphism of the zone adjacent to it, accompanied and followed by fissuring, jointing, and faulting.

(2) Entrance of hot ore-bearing solutions through fissures in the andesite into the adjacent sediments, depositing ore as dikelike masses in fissures in the andesite, as fissure fillings and replacements in the limestone, and as cements in breccias of andesite, limestone, and quartzite. The solutions introduced also garnet, diopside, amphibole, phlogopite, apatite, calcite, quartz, and pyrite. Most of these minerals had also been developed in the limestone by the preceding contact metamorphism. Soda was conspicuously increased in the wall rocks. It is thought that the solutions were pneumatolytic after-effects of the andesite intrusion.

(3) Erosion, developing mountains with andesite cores, encircled by belts of sediments at uniform elevations on the slopes, except where displaced by faults, or where cut back by differential erosion. The areas between the mountains were left with low relief. The ores were exposed and partly eroded, calcite, apatite and perhaps other gangue materials were leached and redeposited below. There was more or less oxidation and hydration of the ores along fissures beneath the surface.

(4) Extrusion of the Tertiary lavas over the entire area, furnishing hot magmatic waters and heat to meteoric waters, and thereby developing coarsely crystalline magnetite and hematite in the ore deposits and especially at the surface, leaching the gangue materials so far as they were left by weathering near the surface, and depositing in the cavities chalcedony and to a slight extent magnetite, hematite, limonite, siderite, chlorite, barite, calcite, galena, and the copper carbonates.

(5) Erosion, reexhuming the andesite mountains from under the lavas and bringing to light the sediments and ores on the slopes; this was accompanied by local surface oxidation and hydration of the ores and leaching of the gangue materials, chiefly calcite, but also apatite. Differential erosion caused the ore in some cases to stand above the adjacent rocks, and in others, where the hard cap was cut off, brought the softer underlying ores well down to the level of adjacent rocks.

(6) Preceding and accompanying (5) occurred faulting of the ore deposits, developing structural relations not in all cases to be distinguished from those determined by faulting before deposition of the ores.

BEARING OF THE THEORY OF ORIGIN UPON FURTHER EXPLORATION.

Exploration has not yet demonstrated the depth of the ore deposits. The greatest known depth is at the Pinto group of pits, south of Iron Mountain, where 130 feet is known from the pits and topography. At the Desert Mound drilling may have gone deeper, but the records are not available to the writers.

If the theory of the writers as to the origin of the ore is correct, there are certain fairly well-based inferences to be drawn as to depth and shape of the ore deposits.

If the ore-bearing fissures in the andesite are true stretch fissures determined by the crystallization of the lavas, it may be inferred that they will show the same features with depth as at the surface; that is, curving, pinching out, branching and occurrence in parallel sets. There seems to be no reason why these vein deposits should not go to a very considerable depth, this being determined by the depth to which fissuring had occurred at the time of the extrusion of the ore-bearing solutions.

The ores at and near the andesite contact are determined in their shape and distribution partly by replacement of limestone, partly by peripheral tension fissures and other joints and faults, partly by faults later than the ore deposition, and finally by erosion. A calculation of the radial shrinkage of the andesite mass in cooling makes it between 200 and 500 feet, depending on the thickness assigned to it. A part of this shrinkage is probably accounted for in the stretch fissures and faults in the andesite. A part of it has with equal probability furnished space for ore deposition at the periphery. At the sides of the andesite these spaces would remain open during and following their development, whereas on the slopes and on top gravity would tend to close them as fast as developed. The deposits therefore should have their maximum width where the contacts are vertical or nearly so and should thin out where the slopes become flatter. The conception of the authors as to the relations of the fissures to the andesite before erosion took place is illustrated in fig. 8. This figure does not take account of modifications of shape of the ore bodies due to replacement of the limestone or due to fissures normal to the andesite periphery, which are believed to be subordinate. Erosion has now cut down sufficiently far on the eastern and southeastern sides of the several laccoliths to expose vertical or nearly vertical contacts. On the southwestern side of the Granite Mountain and Iron Mountain laccoliths the erosion plane has exposed a very gently dipping contact plane between andesite and limestone. The wide extent of the deposits at these places, expecially at the southwestern side of Iron Mountain, is largely due to the fact that the erosion plane is so nearly parallel to the plane of contact. It does not indicate that the deposits are necessarily wider when measured in a direction normal to the contact than they are elsewhere in the district; indeed, if fig. 9 represents approximately the shape of the openings which determined the ore deposition, the deposits here may well have been thinner than elsewhere. Under these conditions vertical faulting has greater effect on the surface distribution.

It follows from the above considerations that the maximum depth of the ore deposits near the contacts may not be greater than the depth to which the andesite-limestone contact extends, and this is determined by the thickness of the andesite laccolith and whether it breaks across the limestone layers or has tilted them up in such a manner that the contact is approximately parallel to the bedding. In view of the fact that the limestone is tilted steeply where erosion has exposed the sides of the laccolith, it may be assumed that the limestone may be in contact with the andesite as far down as the laccolith goes. Therefore the thickness of the laccolith becomes the determining factor. Erosion has allowed no direct means of measuring this thickness in this district, for the bottom is nowhere exposed. A comparison of the hor-

izontal dimensions of these laccoliths with those described by Gilbert
at the Henry Mountains, where the vertical depth also is known, leads
to the conclusion that the depth of the "bell" of the Iron Mountain lac-
colith (the one with outlines best determined) may not exceed 2,500
feet. The other laccoliths are so covered with desert deposits that
their horizontal dimensions are not known, and hence even this means
of determining their depth is not available. Such comparison affords
a very uncertain means of determining the depth of laccoliths in view
of the fact that their shape and size depend so much on the nature
and structure of the rocks intruded, as well as on the relative densities
of the intrusive and intruded rocks. (See pp. 47–48.)

For the deposits resting on gently-dipping slopes, such as those
southwest of Iron Mountain, the maximum depth is likely to be found
in the direction of dip. Vertically they rest directly upon andesite or
upon the contact phase of the limestone, except where they are above
ore-filled fissures in the andesite, in which case the deposit is likely
to narrow considerably in a vertical direction when it reaches the
fissures.

It will be noted that on the western side of Iron Mountain the Cre-
taceous quartzite comes directly into contact with the andesite at an
elevation considerably higher than the limestone-andesite contact on
the southern and eastern sides of the laccolith where the ore is exposed
Ores are found cementing brecciated quartzite, but do not constitute
important deposits. The lack of important ore deposits along this
contact may be explained by the fact that replacement is not possible
in the quartzite and that any fissure veins developed at the contact
through the contraction of the andesite would be immediately closed
by gravity, for the quartzite rests against the andesite with a dip of 35°.
There is nothing in the supposed origin of the ores to preclude the pos
sibility that ore deposits may be found beneath the quartzite along
the limestone-andesite contacts, especially farther down on the steeper
slopes of the andesite. If deposits are there, it may be pointed out
that their size has not been diminished by erosion.

The uniform association of ore with andesite laccoliths in this local-
ity, as well as in the district extending southwest to the Bull Valley
and beyond, outlines the first rule of exploration—that the andesite
laccoliths be found and their boundaries determined. The effect of
the laccoliths upon topography is so marked that this may be done at
a distance of many miles. (See p. 16.) From high points in the Iron
Springs district it is easy to determine the southwestward extension of
the laccolithic area, and therefore of the possible ore-bearing area.

The laccolith determined, its contact with the adjacent sediments
should be carefully followed.

The location of iron-ore deposits usually makes itself evident on
the weathered surface, but not infrequently the mass of débris which

has shifted down the slopes makes it impossible to determine the true outline of the deposit without sinking pits. Where iron-ore fragments are found in the wash at the surface it may be assumed that they came from farther up the slope. Following the wash up the slope, a point will be reached where no iron fragments are to be seen, usually indicating that the upper edge of the deposit has been passed; but it has been found in a few localities that the overwash from the upper slopes has been so thick and heavy that it completely obscures the upper side of the ore deposits, and the first iron-ore fragments appear some feet or yards farther down the slope. The presence of a few fragments, or even of a single fragment, of iron ore in the wash is often sufficient to indicate the existence of an ore deposit several hundred yards away, which may be found by following up the wash and carefully watching its change in iron content.

Where the laccolith and sedimentary rocks are found in direct contact it does not necessarily follow that ore will not be found deeper down along the contact. Replacements are usually irregular, and the source of the solutions is not from above. So far as the ores are fillings of fissures developed around the periphery of the andesite by its crystallization, it is easily conceivable that these openings would be irregular, both horizontally and vertically, and that where the dip of the laccolith contact is low, gravity might close them altogether, so that the appearance or nonappearance of ore on the erosion surface would be determined merely by the extent to which the erosion surface had cut down.

In underground exploration the fact should not be lost sight of that the deposit may show the same range of irregularity with depth that it does on the erosion surface; in other words, that all the factors known to have determined the peculiarities and shapes of deposits on the erosion surface, which are discussed in this paper, should be taken account of in the underground exploration.

CHAPTER VIII.

COMPARISON OF IRON SPRINGS IRON ORES WITH OTHER IRON ORES.

BULL VALLEY DISTRICT.

The Bull Valley district lies about 25 miles to the southwest of the Iron Springs district, extending from Garden Springs on the northeast southwestward to Bull Mountain and 40 or 50 miles beyond. (See fig. 11.) The district, which has only recently been explored
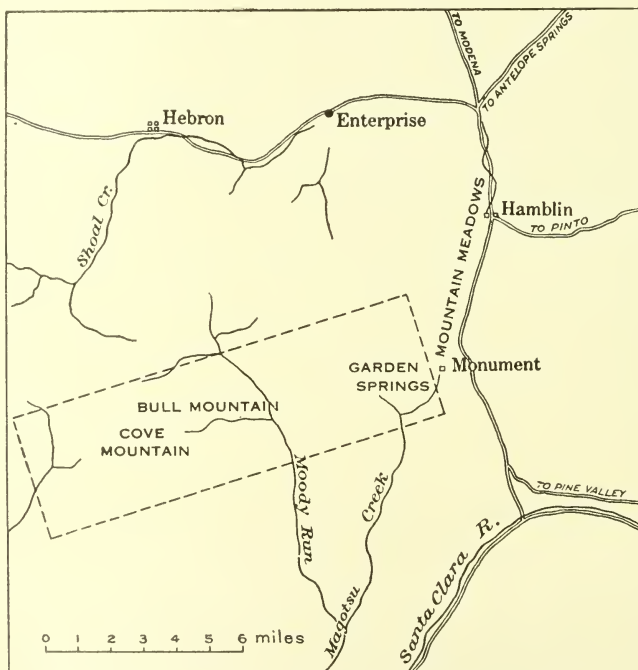
FIG. 11.—Sketch map of Bull Valley district, Utah.

and staked, is much more difficult of access than the Iron Springs district and is consequently less well known. It may be reached from the Iron Springs district by team by way of Pinto, Hamblin, and Enterprise, or on horseback by way of Pinto, Hamblin, Mountain

Meadows Valley, Magotsu Creek, and Moody Run. The nearest railway station is Modena, 28 miles distant by way of Enterprise. The area is covered by the St. George topographic sheet of the Powell Survey (1891), but the map is so imperfect and generalized that it is of little use.

The principal ore deposits lie several miles below the headwaters of Moody Run, which empties into Magotsu Creek 10 miles below the Mountain Meadows. From this point they extend eastward about 3 miles to Garden Springs, located a short distance west of the Mountain Meadows monument, the site of the famous Mountain Meadows massacre. To the southwest, deposits occur on Bull Mountain 2 or 3 miles distant and on Cove Mountain an equal distance beyond.

The essential geological features of the district are the same as those in the Iron Springs district—a series of laccoliths with sediments dipping quaquaversally away from them, surrounded and overlain by flat-lying lavas, the whole being bounded on north and west by later flows of basalt. The contour of the district is rougher than that of the Iron Springs district and the evidences of volcanism are more conspicuous on account of the presence of basalt flows and cinder cones. The general aspect is barren and forbidding. The same topographic and geologic conditions are said to extend for about 40 miles to the southwest into Nevada, and ores are reported from this area.

The ore deposits were examined in their discontinuous occurrence between the headwaters of Moody Run on the west and Garden Springs on the east, and were found to be similar in almost every feature to those of the Iron Springs district. The principal deposits lie within the andesite associated with limestone fault blocks, and subordinate ones follow the main contact of andesite and limestone, which crosses Moody Run in a northeast-southwest direction, dipping to the southeast. Flat-lying flows fringe the ore-bearing areas. On the south are acidic flows and tuffs, on the north acidic flows and tuffs and basalts. A white band near the base of the acidic lavas is very conspicuous and for most of the district is sufficiently near the limestone-andesite contacts to make it useful to explorers as a guide in locating the ores.

The greatest width of ore observed at the surface was 115 feet. However, it was not sufficiently well exposed to make it certain that this 115 feet was continuous ore. This particular deposit has a length of approximately 700 feet.

The iron is both magnetite and hematite, as in the Iron Springs district, but the hematite on the lower slopes takes on a fine granular texture and a steel-blue color which is not seen in the Iron Springs district.

The composition of the ore at the surface, as sampled by Lerch Brothers, is as follows:

Composition of the Bull Valley district ores.

[Analyst, Fred Lerch, Biwabik, Minn.]

	Iron.	Phos-phorus.
Across 150 feet, Pilot No. 9	58.98	0.195
Across 250 feet, Pilot No. 8	62.38	.217
Across 60 feet, Pilot No. 7	62.06	.163
Pilot No. 12	66.40	.072
Across 40 feet, Pilot No. 7	64.13	.434

There has been a small amount of pitting, trenching, and tunneling, but these amount only to scratches in the upper parts of the deposits.

DEPOSITS OF SIMILAR ORIGIN IN OTHER DISTRICTS.

Ores similar to those of the Iron Springs district, consisting principally of magnetite in veins (not magmatic segregations in situ), in igneous rocks or near the contact of igneous rocks and limestone or in both combinations, are known at many localities in western North America, as follows:

In Mexico, where nearly all the iron ores are of this character, their distribution and occurrence being summarized by Hill [a] and by Aguilera.[b] The Durango deposit is described in a number of papers.

In several localities in San Bernardino County, Cal.,[c] and in the Redding quadrangle of northern California.[d]

In Lyon County, Nev., and in several other localities in the Great Basin.[e]

In Stevens County, northeastern Washington,[f] Texada and Vancouver islands, British Columbia,[f] and Kamloops, British Columbia.[f]

At Fierro [g] and Chupadera Mesa, New Mexico.[h]

In the Taylor Peak, White Pine, and Cebolla districts in Pitkin and Gunnison counties, Colo.[i]

At Iron Mountain, Missouri.[j]

This list of localities is far from complete and no attempt is made to cite all the publications concerning the districts named.   It is the

a Hill, R. T., The occurrence of hematite and martite iron ores in Mexico: Am. Jour. Sci., vol. 45. 1893, p. 112.

b Aguilera, José G., The geographical and geological distribution of the mineral deposits of Mexico: Trans. Am. Inst. Min. Eng., vol. 32, 1902, pp. 503–505.

c Leith, C. K., Iron ores of the western United States and British Columbia: Bull. U. S. Geol. Survey No. 285, 1906, pp. 194–200.

d Diller J. S., Iron ores of the Redding quadrangle, California: Bull. U. S. Geol. Survey No. 213, 1903, pp. 219–220.

e Manuscript notes furnished authors.

f Leith, C. K., op. cit., pp. 195–196.   Report on the iron ores of the coast of British Columbia, by the Provincial Mineralogist: Dept. of Mines, Victoria, B. C., 1903, 30 pp.

g Manuscript furnished the authors by R. W. Hills.

h Keyes, Charles R., Iron deposits of the Chupadera Mesa: Eng. and Min. Jour., vol. 78, 1904, p. 632.

i Manuscript notes, summers of 1905 and 1906, Van Hise, Leith, Harder, and Ward.

j Nason, Frank L., A report on the iron ores of Missouri: Missouri Geol. Survey, vol. 2, 1892, pp. 1–365.

purpose simply to emphasize the widespread distribution of deposits of these types and to cite some of the descriptions.

From the fact that the ores of these districts have certain essential features in common, it does not necessarily follow that the origin of the ores has been the same for all. Certainly there has not been enough detailed work on the ores of many of the localities named to warrant final conclusions as to their origin. Nevertheless, the similarities in these deposits are such as to suggest similarity of origin as a guiding hypothesis for study, and such results as have been obtained to the present time tend strongly to support this hypothesis rather than to break it down.

Several deposits which have been examined personally by the writers or associates are unhesitatingly assigned an origin similar to that here presented for the Iron Springs district of Utah. These include the Taylor Peak and White Pine ores of Colorado, studied by Van Hise and Leith and mapped in detail by Harder and Ward; the Cebolla district of Colorado, examined by Van Hise and Leith; the Bull Valley district of Utah, examined by Leith and Harder; and certain of the deposits in northeastern Washington, Texada and Vancouver islands, the Kamloops district, British Columbia, and San Bernardino County, California, examined in reconnaissance by Leith. All of these ores, in hand specimen and slide, show intimate association with anhydrous silicates and have structural relations to wall rock essentially similar to those of the Iron Springs district, though differing from these in structural and lithologic details.

Among the men who have given particular attention to the economic geology of the west emphasis has been uniformly placed on the genetic association of ores and igneous rocks along contacts, but there has been lack of agreement as to the real significance of the association—as to whether the igneous rocks have contributed both solutions and ores, or only hot water which has leached the ores from the adjacent rocks, or only heat which has enabled meteoric waters to leach ores from the adjacent rocks and redeposit them; whether the solutions have been liquid or gaseous; what their direction of movement has been, etc. In recent years there has been a rapidly growing tendency to emphasize the importance of liquid and gaseous solutions coming directly from the igneous rocks and bringing the ores with them. In discussions of genetic classifications of ores by Lindgren,[a] Weed,[b] Spurr,[c] and others, ore deposits developed along igneous contacts by "pneumatolytic after-action" find con-

[a] Lindgren, Waldemar, The character and genesis of certain contact deposits: Trans. Am. Inst. Min. Eng., vol. 31, 1902, pp. 226–244.

[b] Weed, W. H., Ore deposits near igneous contacts: Trans. Am. Inst. Min. Eng., vol. 33, 1903, pp. 715–746.

[c] Spurr, J. E., A consideration of igneous rocks and their segregation or differentiation as related to the occurrence of ores: Trans. Am. Inst. Min. Eng., vol. 33, 1903, pp. 288–340.

spicuous place. Iron-ore deposits have been included in this class largely because of the classic work of Vogt on the Christiania deposits. Individual deposits of western contact iron ores have not been specifically referred to this class because they have not been sufficiently known. The pneumatolytic origin of the Iron Springs ores now seems to be sufficiently well based and their similarity to other western contact iron ores sufficiently close to make it possible to assign a pneumatolytic origin to this general class of ores with some confidence.

The direct development of magnetite in pegmatitic veins is described by Spurr in the Georgetown quadrangle of Colorado. The case is conclusive, for magnetite crystals of considerable size are found in the interior of unaltered pegmatite veins.

Spencer[a] reached the conclusion that certain of the New Jersey magnetites are essentially pegmatitic in their origin. In addition to the Christiana deposits, Vogt[b] cites other European deposits[c] which he regards as of the same origin. Beck[d] does the same. Of interest also in this connection is the recent work of Stutzer[e] on the ores, which he regards as dikes, of the Kirunavaara and Luossavaara districts in northern Sweden, and the still more recent work of Sjögren[f] on the Scandinavian iron ores.

The prevalence of an iron cap or gossan above sulphide deposits in fissure veins or along the contact of igneous rocks and limestones is responsible for a widespread view that western iron ores of this occurrence will be found to grade down into sulphides; that the ores are the oxidized portions of sulphide veins which may have originated in the manner here outlined for the Iron Springs district; that the ores therefore have an ultimate igneous source to the same extent as the sulphide deposits, whatever this may be. Reasons are given on another page for the belief that the Iron Springs magnetite was deposited directly from hot solutions and not as an alteration product of sulphide, but that simultaneously there were deposited small and variable amounts of pyrite. So far as the writers know, there is no evidence of increase in sulphur content in depth in any of the ores of this class in the localities cited, beyond perhaps the first few inches or few feet, from which the sulphide, originally deposited with the

a Spencer, A. C., Genesis of the magnetite deposits in Sussex county, N. J.: Min. Mag., vol. 10, 1904, pp. 377–381.

b Vogt, J. H. L., Problems in the geology of ore deposits: Trans. Am. Inst. Min. Eng., vol. 31, 1902, pp. 125–169.

c Northern Sweden, Kristiania district, southern Hungary, Island of Elba and Dieletti, France.

d Beck, Richard, The nature of ore deposits, translated by W. H. Weed, 2 vols., New York, 1905, 685 pp.

e Stutzer, O., Die Eisenerzlagerstätte Gellivare in Nordschweden: Zeitschr. für prakt. Geol., bd. 14, No. 5, May, 1906, pp. 137–140; Die Eisenerzlagerstätten bei Kiruna: Zeitschr. prakt. Geol., bd. 14, No. 3, March, 1906, pp. 65–71.

f Sjögren, Hjalmar, The geological relations of the Scandinavian iron ores: Trans. Am. Inst. Min. Eng., vol. 38, 1908, pp. 877–946.

ore, has been leached by weathering. It must be remembered, however, that no one of these deposits has been opened up sufficiently to demonstrate their character in depth.

The theory that iron ores at the contacts of igneous rocks and limestone have developed entirely by the action of meteoric waters from above, leaching ores from the adjacent rocks, has not been without supporters. This is the view held by Hill for the Durango deposit. The senior author presented this theory as possibly applicable to the Iron Springs deposits of Utah in an earlier publication. It would be entirely premature to exclude this hypothesis for all iron ores in fissure veins in igneous rocks or along their contacts with limestone, especially where these ores are largely limonite and apparently lack heavy anhydrous minerals, as in some of the deposits of northeastern Washington. It is usually where the ores are hard crystalline magnetites and hematites, intimately associated with the anhydrous silicates and adjacent to or within igneous rocks, that there is reasonable probability that the origin of the ores may be ascribed to the hot solutions coming from the igneous rocks.

STRUCTURAL DISSIMILARITIES OF THE IRON SPRINGS DEPOSITS TO OTHER CLASSES OF IRON-ORE DEPOSITS.

The structural features in which the iron-ore deposits of the Iron Springs district differ from ores of sedimentary origin, like the Lake Superior and Clinton ores, are obvious to all familiar with the great classes of iron-ore deposits, but for those who are not so familiar an elementary comparison may be of interest.

The Clinton hematites of Alabama and elsewhere are bedded deposits with all the stratigraphic and structural characteristics of sedimentary rocks. Given a bed, it may be expected to extend in strike and dip, thicken and thin, with about the same degree of uniformity as may be observed in other sedimentary layers, such as limestone or shale adjacent. Its structure also, as shown by strike and dip, is governed by the same laws as other deformed beds. It is thus frequently possible to determine with some certainty extensions of deposits for many thousands of feet. The Iron Springs deposits can not be followed or extensions calculated with any such certainty.

The Lake Superior iron-ore deposits are more or less irregular concentrations in a sedimentary "iron formation." The iron ores make up a very small per cent—less than 2—of the mass of the iron formation. The iron formation originally consisted of iron carbonate or iron silicate, and was altered to iron ore, ferruginous chert, or jaspilite, but retained its bedding. The structure and stratigraphy of the iron formation may be worked out as fully as for limestone or quartzite. Exploration is limited to the iron formation, and the presence of an

iron formation is regarded as a prerequisite for exploration for iron ore. The Iron Springs deposits lack an associated sedimentary iron formation to serve as a guide for exploration, though there are locally present lean phases of ores for which the term "iron formation," without genetic significance, might be appropriate. The deposits themselves in the Lake Superior region rest in structural basins which determine for each district certain uniformities and peculiarities of shape for the ore deposits for that district. For the Lake Superior region as a whole the variety of shapes of ore deposits is probably greater than that in the Iron Springs district, but the Iron Springs deposits probably have a shape and size which can be less safely predicted in advance of exploration than can those of the deposits of any one of the Lake Superior districts. They have, however, one considerable advantage in that they are largely exposed on the erosion surface, whereas the Lake Superior deposits are in great part covered by glacial drift.

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INDEX.

O

ESCALANTE   DESERT

Upper Pt

ANTELOPE RANGE

Antelope Sprs

Reservoir Creek

Church Ranch

Iron Springs BM

RUSH LAKE VALLEY

Lindsay Hill

Swett Pt

Desert Mound

Eightmile Pass

Bowers Ranch

CEDAR BOTTOMS

Iron Springs Canyon

Eightmile Hills

Eightmile Springs

IRON MILLS

THE   BOTTOMS

Snake Lake

HOMESTAKE MINE

Oak Springs Flat

Mt Iron

Oak Springs

Iron

Mt Clarou

BM 5690

Leach Canyon

McConnells Ranch

Milner Hill

Blowout Hollow

Duncan Ranch

Crystal Sprs

Blowout Hill

Wash

Mud Springs

Birch Canyon

Pole Canyon

Colton Canyon

Lizzette Canyon

HARMONY   MOUNTAINS

TOPOGRAPHIC MAP OF IRON SPRINGS QUADRANGLE, UTAH

Scale 62500

TRUE NORTH

APPROXIMATE MEAN
DECLINATION 1905

4 miles

5 kilometers

Contour interval 50 feet
Datum is mean sea level
assuming elevation of Lund railroad station as 5093

ESCALANTE DESERT

LEGEND

SEDIMENTARY ROCKS

Qal — Lake, stream, and outwash deposits (gravel, sand, and clay)

Qpo — Conglomerate

Tec — Claron limestone (including some conglomerate and sandstone)

Kp — Pinto sandstone (including some shale and conglomerate)

Kpl — Limestone lenses in Pinto sandstone

Ch — Homestake limestone (Nar limestone)

— Iron ore deposits

IGNEOUS ROCKS

ba — Biotite-hornblende-pyroxene andesite (andesite with volcanic breccia and conglomerate)

lr — Late tuffaceous rhyolite (rhyolite tuff with agglomerate at base)

bd — Biotite dacite

pa — Pyroxene andesite (agglomerate and breccia)

ltr — Latest trachyte

ha — Hornblende andesite (agglomerate and breccia)

ltr — Later trachyte

er — Early tuffaceous rhyolite

etu — Early trachyte (upper thin-layered part)

et — Early trachyte

la — Laccolithic biotite andesite

— Faults

— Dike

— Strike and dip of sedimentary strata

— Conglomerate beds

Eocene · Pleistocene · Recent

Late Miocene

Early Miocene

SECTIONS ALONG LINES A-A', B-B', AND C-C'
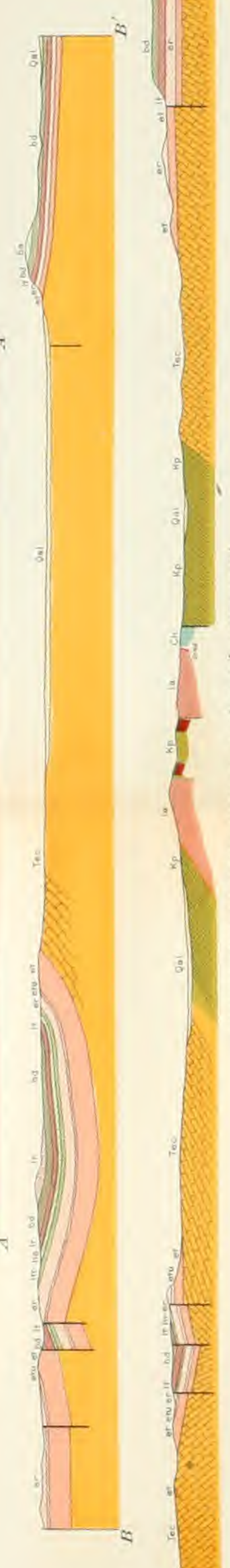
GEOLOGIC MAP AND SECTIONS OF IRON SPRINGS QUADRANGLE, UTAH

1907

Scale

HARMONY MOUNTAINS

WAR EAGLE AND MARSHALL CLAIMS, THREE PEAKS
Scale
0   500   1000 feet

GREAT WESTERN CLAIM, THREE PEAKS
Scale
0   500   1000 feet

MC GARRY CLAIM,
THREE PEAKS
Scale
0   500 feet

LEGEND

Pinto sandstone

Homestake limestone

Metamorphosed Homestake
limestone

Iron ore deposits
and veins

Laccolithic andesite

Conglomerate

Rock outcrops

Faults and probable faults

Strike and dip of bedding

Strike and dip of secondary
structure

Strike and dip of contact

Washes

Test pits and shafts

Trench

Tunnel

Claim stake

Thickness of ore veins
in inches and feet
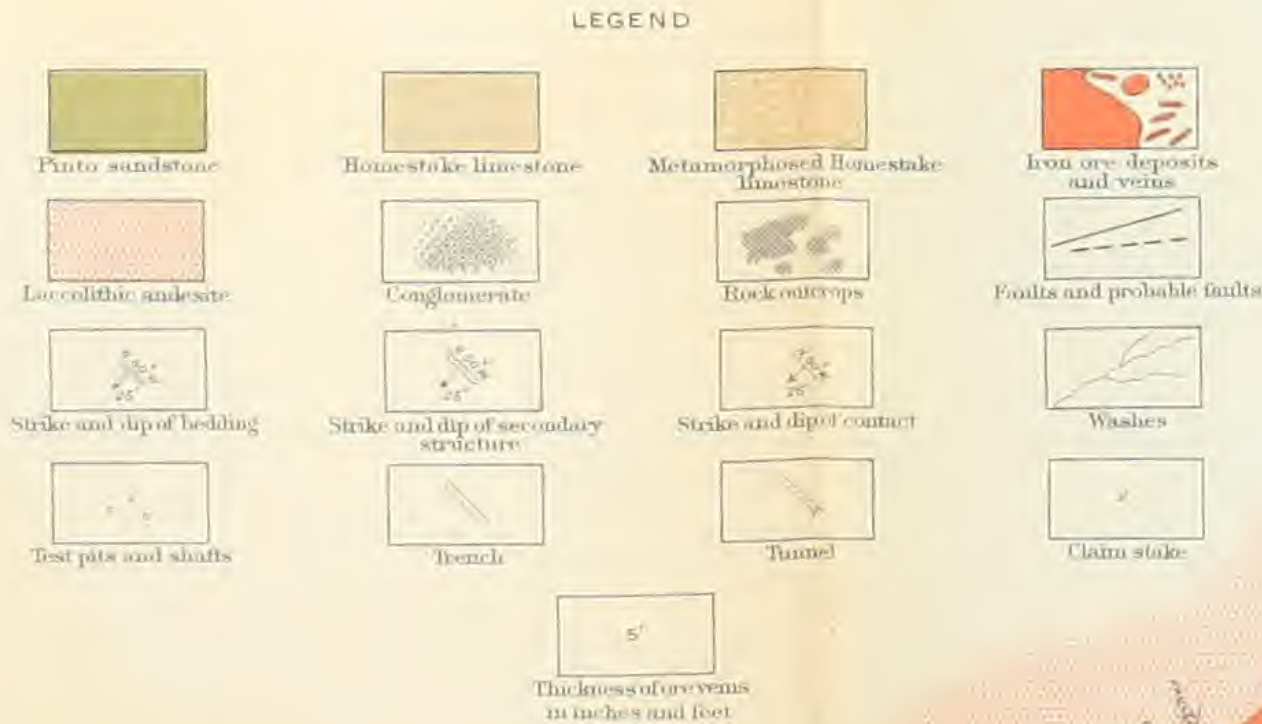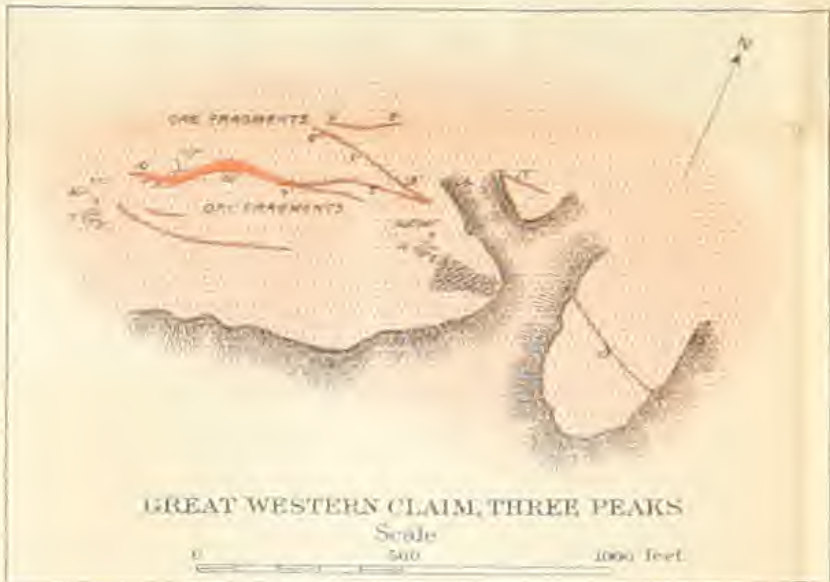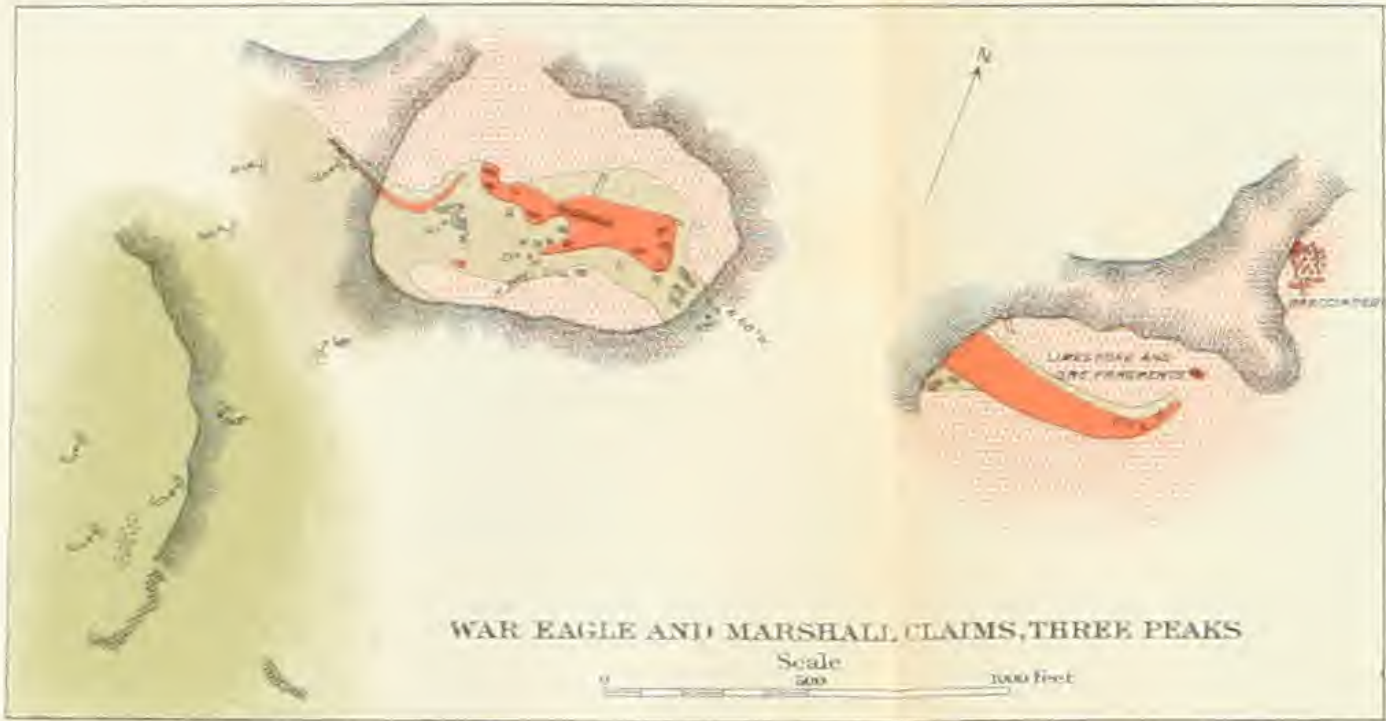
GRANITE MOUNTAIN
Scale
0   500   1000 feet

DETAIL MAPS SHOWING IRON ORE DEPOSITS
1907

LEGEND

Pinto sandstone

Homestake limestone

Metamorphosed Homestake limestone

Iron ore deposits and veins

Laccolithic andesite

Conglomerate

Rock outcrops

Faults and probable faults

Strike and dip of bedding

Strike and dip of secondary structure

Washes

Test pits and shafts

Trench

Tunnel

Claim stake

Mining shack

Road

5'

Thickness of ore veins in inches and feet

N

DETAIL MAP OF THE IRON ORE DEPOSITS ON THE EAST SLOPE OF IRON MOUNTAIN

Scale
0   500   1000   1500   2000 feet

1907

A. HOEN & CO. BALTIMORE, MD.

LEGEND

Pinto sandstone

Homestake limestone

Metamorphosed Homestake limestone

Iron ore deposits

Laccolithic andesite

Conglomerate

Rock outcrops

Faults and probable faults

Strike and dip of bedding

Strike and dip of secondary structure

Strike and dip of contact

Washes

Test pits and shafts

Trench

Tunnel

Mining shack

DESERT MOUND

DRILL HOLE

N 88°W

LIMONITIC MARBLE

SHALE AND BRECCIATED LIMESTONE

BETWEEN CRYSTAL SPRINGS AND OAK SPRINGS, IRON MOUNTAIN

CRYSTAL SPRINGS

DETAIL MAPS SHOWING IRON ORE DEPOSITS

1907

LEGEND

Pinto sandstone

Homestake limestone

Metamorphosed Homestake limestone

Iron ore deposits and veins

Laccolithic andesite

Conglomerate

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Faults and probable faults

Strike and dip of bedding

Strike and dip of secondary structure

Washes

Test pits and shafts

Trench

Tunnel

Claim stake

Mining shack

Road

Thickness of ore veins (inches and feet)

Triangulation station
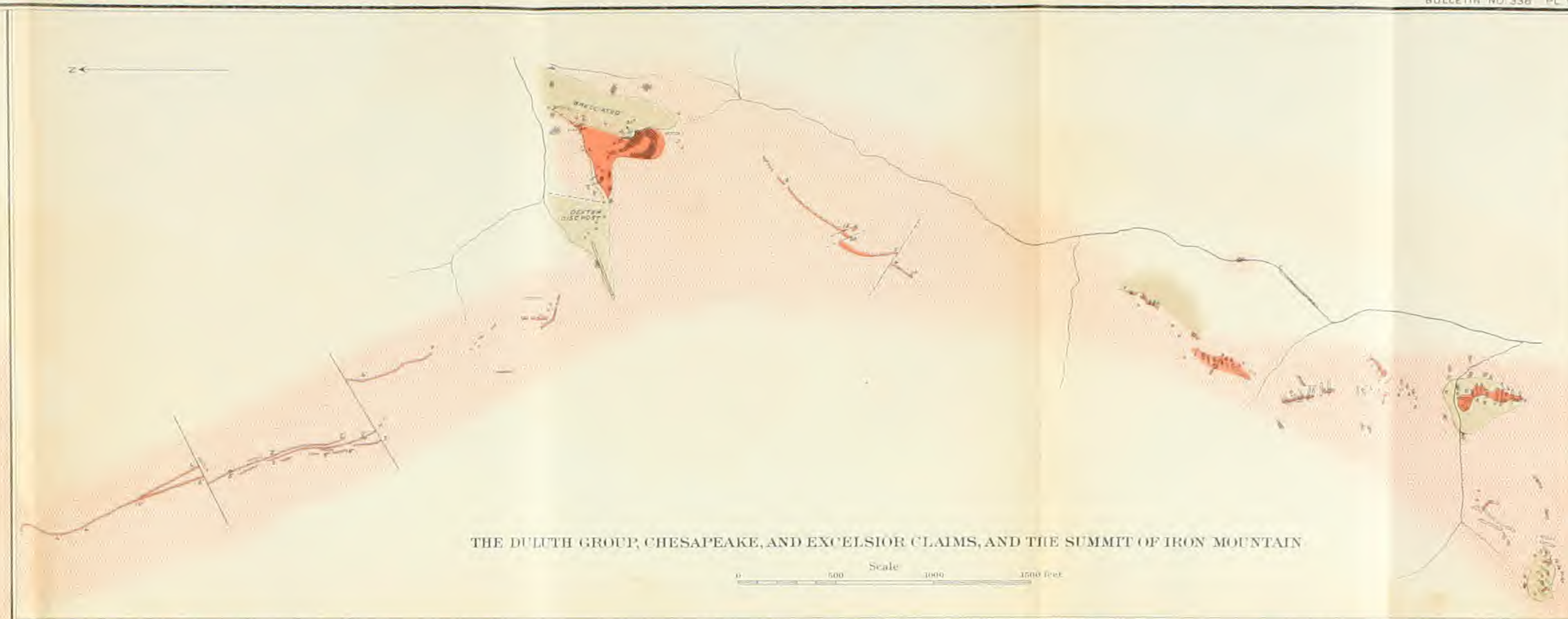
THE DULUTH GROUP, CHESAPEAKE, AND EXCELSIOR CLAIMS, AND THE SUMMIT OF IRON MOUNTAIN

Scale

0   500   1000   1500 feet

THE SOUTH AND WEST SLOPES OF IRON MOUNTAIN

Scale

0   500   1000   1500 feet

DETAIL MAPS SHOWING IRON ORE DEPOSITS
1907